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226

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FOREWORD /3

Published methodological materials on ergonomics were prepared by the All-Union Scientific-Research Institute for Aesthetic Styling in Engineering (VNIITE) jointly with other organizations doing ergonomic research, and which have been successful in utilizing their results in industry. This publication is yet another step along the road to writing a handbook on planning ergonomics (see Ergonomics: Principles and Recomendations, Issue No. 1, Moscow, VNIITE, 1970).

There are two approaches that should be taken to the solution of the problem of optimization of job performance. One concerns adapting engineering to the human factor, the other adapting man to the working conditions. They are interrelated, and optimum solutions of this problem can be found during the process of complex planning of the external and internal agents that cause man to perform. This edition is devoted to the basic questions of planning the internal agents that cause man to perform, and one of the most complex problems here is that of investigating conditions and ways to form vocational usefulness. Arranging the materials generalizing some of the research in this field, and experience in making practical application of it, one must, once again, become aware of the need for a responsible, and scientifically founded approach to vocation selection, which, to some extent, determines man's fate.

This issue devotes a great deal of space to the psychophysiological analysis of man's job performance. Functional-algorithmic analysis, which permits making a quantitative analysis of performance by using a system of criteria, is extremely important in planning performance. The materials in this issue, overall, indicate that the psychophysiological analysis of job performance, and the vocation profile developed using that analysis as a base, should serve as the point of departure for ergonomic research and then, later on, become the basis of all /4 work done along the lines of adapting engineering and working conditions to man, and vice versa. The development and perfection of this analysis is an important condition for the founding of ergonomics as a planning discipline.

The materials in this collection have been drawn upon to contribute to improving the ergonomic culture of artist-designers and technical specialists who often tend to make a fetish of so-called "prescribing" ergonomics. The materials published herein can be of interest to ergonomists and engineering psycholo-

gists because they focus attention on experimental methods of doing research, and on mathematical ways to describe things, as well as on non-experimental methods which, as is known, require of the researcher at least asmuch, if not more, creative thought than does the laboratory experiment, as well as lengthy and painstaking collection of material and skill in processing that material scientifically.

TABLE OF CONTENTS

Foreword iii

Chapter 1. Principles of the Ergonomic Description of Operator Performance 1

1. Ergonomic Indices 1
2. Ways to Obtain the Original Information Needed to Describe Performance 10
3. Procedures for Operator Performance Synthesis, and Forms in which Performance Can Be Described 21
4. Determination of Personal Qualities Most Corresponding to Vocation Performance 26

References 29

Chapter 2. Some Methods of Ergonomic Analysis of Performance Under Production Conditions 32

1. Questioning Methods 33
2. Subjective Observation Methods 38
3. Objective Observation Methods 44

References 73

Chapter 3. Selection, Education, and Training of Operators for the "Man-Machine" System 76

1. Fundamental Principles of Vocation Selection ... 77
2. Original Propositions for the Development of a Vocation Selection System 79
3. Procedures for Studying Personal Vocation Aptitudes 82
4. Principles and Rules for the Classification of Personnel Undergoing Vocational Selection 92
5. Some Organizational and Procedural Recommendations for Psychophysiological Selection 103
6. Fundamental Principles and Conditions for Increasing the Effectiveness of Operator Training 108
7. Influence of Special Physical Conditioning on Effectiveness of Operator Training 116

References 120

Chapter 4. Objective Monitoring of the Level of Training of Operators in the "Man-Machine" System 123

1. The Role and Place of Objective Monitoring in the Operator Training System 123

2. Selection and Justification of the Indices for Evaluating Operator Training Level 125
3. Possible Monitoring Variants and the Mathematical Apparatus for Evaluating the Quality of the Work Done by Operators 130
References 138

Chapter 5. Procedure for Processing Psychophysiological Parameters 139

1. Electroencephalogram (EEG) 140
2. Electrooculogram (EOG) 144
3. Galvanic Skin Reaction (GSR) 145
4. Pulsimetry 147
5. Electropneumogram (EPG) 148
6. Electromyogram (EMG) 149
References 154

Chapter 6. Psychological Stress of Space Flight 155

1. Principal Psychological Stressors. Hypodynamia 158
2. Problems Associated with Long Periods of Activity by Autonomous Groups 164
3. Problems of Motivation and Emotional Reactions .. 167
References 169

Chapter 7. Operator Training Aids 170

1. General Requirements for Training Aids 170
2. Classification of Training Aids 176
3. Generalized Typical Structural Arrangement of the Training Aid 183
References 196

Chapter 8. Mathematical Models of Trainability of the Operator in the "Man-Machine" System 198

1. Mathematical Trainability Model Based on the Cybernetic Description of Operator Activity 202
2. The Use of the Mathematical Trainability Model for Practical Purposes 214
References 219

CHAPTER I

PRINCIPLES OF THE ERGONOMIC DESCRIPTION OF OPERATOR PERFORMANCE

The solution of any ergonomic problem, including engineering psychology problems, supposes an analytical description of the job performance of the operator based on annumber of indices: psychological, physiological, hygienic, and others. This description as a whole is called a vocation profile, and is understood to mean the development of the content and nature of the psychic and psychophysiological functions, and combinations of them, inherent in each type of job performance. Many of the methods of psychophysiological analysis of job performance are indebted to labor psychology and physiology for their origin. This chapter reflects everything of value previously gathered in this field.

Ergonomics cannot yet be satisfied by these methodological principles alone, principles that have become a part of labor psychology and physiology. Recent attempts have been made to further perfect the methods used for the psychophysiological analysis of job performance. There are a great many difficulties involved in the development of new methods to use in vocation profiling. One such difficulty is that ergonomics does not have firm terminology. Consequently, descriptions of new methods for psychophysiological analysis of job performance in this chapter will introduce definitions without pretending that they are the final, and definitive, formulation. Another difficulty is the need to obtain qualitative, as well as quantitative, characteristics of performance. This chapter also reflects the attempts made to overcome this difficulty.

1. Ergonomic Indices /6

There are three classes of indices that can be used to provide an ergonomic description of operator performance:

(1) system properties and the makeup of the job process; that is, the characteristics of the properties of the "man-machine" system, and the set of psychic and physiological processes involved in the particular type of performance;

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*) Numbers in the margin indicate pagination in the foreign text.

(2) the specific stress determining the dynamics and the intensity of the psychophysiological processes at the basis of man's performance;

(3) nonspecific stress, characterizing the status of the psysiological and psychic functions ensuring that the body will function as the job processes are carried out.

Table 1 lists the set of indices for the properties of the "man-machine" system, and the composition of the job process. The data listed are those obtained by analyzing the performance of a pilot (p), an aircraft dispatcher (a.d.), an aviation mechanic (a.m.), and a driver (d).

The classification indices, and their significance (properties, features), have a hierarchical structure: type; class; specie, form, based on existing opinions as to the characteristics of the "man-machine" system and the processes involved in the conversion of information by the man-operator [2, 6, 10, 11, 17, 26, 28]. The place of the index, or of its significance, in this structure is number coded (C-1.0.0.0; I-1.2.1.0, etc.).

The concept of composition weight, characterizing in relative units the share of a particular property (process) in performance accomplished, can be used to measure the significance of the index. Measurement is made in scale units: 0, 1, 2, 3, 4, or 5. The original magnitude for this evaluation is the time required for the particular process. For example, if an aircraft dispatcher spends 20 percent of his time on duty converting a direct closure into information with discrete reactions (C-2.3.0.0; I-1.0.0.0), and 60 percent of his time converting into reproducible logic operations (I-2.1.3.0), the composition weight of I-1.0.0.0 will be 1, and that of I-2.1.3.0 will be 3. The rest of the classes of conversion of information will be covered by 1. The sum can be larger than 5 if some of the processes take place simultaneously.

The system using units for purposes of evaluation results in the obtaining of an integral evaluation of concrete performance that considers system properties, the composition of the job process, and its stress.

A conventional (scale of six) scheme that fixes the degree to which the psychophysiological processes deviate from the optimum can be used to measure

TABLE 1. ERGONOMIC INDICES FOR THE PROPERTIES OF THE "MAN-MACHINE" SYSTEM AND THE COMPOSITION OF THE JOB PROCESS

/7

Hierarchical number for the classification index (C)	Classification Index	Hierarchical number for the significance of the index (I)	Significance of the index (property, criterion)	Composition weight, units P	AD	AM	D
1	2	3	4	5	6	7	8
1.1.0.0	Characteristics of the control system intermediate between man and the object of the job						
		1.0.0.0	No intermediate control system	0	0	4	1
		1.1.0.0	Direct effect of human effectors	0	0	1	1
		1.2.0.0	Effect of simple work tools	0	0	4	4
		2.0.0.0	Intermediate control system available	5	5	1	4
		2.1.0.0	Low-rank	5	1	5	5
		2.1.1.0	Machine	4	1	3	4
		2.1.2.0	Man	1	1	2	1
		2.2.0.0	Multi-rank	0	5	0	0
		2.2.1.0	Machine	0	2	0	0
		2.2.2.0	Man	0	3	0	0
		2.2.3.0	Small collective (group)	0	1	0	0
		2.2.4.0	Large collective	0	0	0	0
1.2.0.0	Organization of movement of information in the system						

/8

Hierarchical number for the classification index (C)	Classification Index	Hierarchical number for the significance of the index (I)	Significance of the index (property, criterion)	Composition weight, units P	AD	AM	D
1	2	3	4	5	6	7	8
1.2.1.0	Characteristics in terms of number of channels	1.0.0.0	Single-channel	0	0	4	0
		2.0.0.0	Multi-channel	5	5	1	5
		2.1.0.0	Integrated	4	3	1	4
		2.2.0.0	With switches	1	2	4	1
1.2.2.0	Characteristics in terms of quality of feedback	1.0.0.0	With complete information	4	4	5	5
		2.0.0.0	With deficit information	1	1	0	0
		2.1.0.0	With inadequate volume of information	1	1	0	0
		2.2.0.0	With time lag	1	1	0	0
2.0.0.0	Characteristics of information processing processes						
2.1.0.0	Characteristics of input signals						
2.1.1.0	Modality	1.0.0.0	Visual	5	5	5	5
		2.0.0.0	Audible	2	5	3	2
		3.0.0.0	Kinesthetic	4	1	1	3
		4.0.0.0	Tactile	1	0.5	2	1
		5.0.0.0	Vibration	1	0	1	1
		6.0.0.0	Temperature	0	0	1	1
		7.0.0.0	Olfactory-taste	0.5	0	0	0

Hierarchical number for the classification index (C)	Classification Index	Hierarchical number for the significance of the index (I)	Significance of the index (property, criterion)	Composition weight, units P	AD	AM	D
1	2	3	4	5	6	7	8
2.1.2.0	Form of representation	1.0.0.0	Indirect	3	0	4	4
		2.0.0.0	Code	2	5	1	1
		2.1.0.0	With an invented alphabet	1	3	1	0
		2.2.0.0	With a conventional alphabet	4	2	4	5
2.2.0.0	Characteristics of signals-engrams	1.0.0.0	Nonactivated engrams (automatic performances)	4	2	3	4
		2.0.0.0	Activated engrams	3	3	2	1
		2.1.0.0	In the form of sample representation	4	3	3	4
		2.1.1.0	Visual	5	2	3	2
		2.1.2.0	Spatial	5	4	5	5
		2.1.2.1	Two-dimensional	1	3	3	5
		2.1.2.2	Three-dimensional	5	4	0	5
		2.1.3.0	Time	4	2	2	0
		2.2.0.0	In concept form	1	2	2	1
		2.3.0.0	In program (plan, algorithm) form	4	5	2	2

/9

Hierarchical number for the classification index (C)	Classification Index	Hierarchical number for the significance of the index (I)	Significance of the index (property, criterion)	Composition weight, units P	AD	AM	D
1	2	3	4	5	6	7	8
2.3.0.0	Characteristics of operations involved in information conversion	1.0.0.0	Direct closure operation	4	2	3	4
		1.1.0.0	Discrete	1	5	5	1
		1.2.0.0	Tracing	4	0	0	4
		2.0.0.0	Transforming operations	3	3	2	1
		2.1.0.0	Reproductive	4	4	4	4
		2.1.1.0	Recoding	4	4	1	0
		2.1.2.0	Grouped	4	4	4	4
		2.1.3.0	Logic	4	4	3	2
		2.1.4.0	Calculating	1	1	1	1
		2.2.0.0	Productive	1	1	1	1
		2.2.1.0	Search-associative	1	1	1	1
		2.2.2.0	Heuristic	0	0	0	0
2.4.0.0	Characteristics of final effect (action)	1.0.0.0	Effector	5	2	4	5
		1.1.0.0	Motor-dynamic	5	1	4	5
		1.1.1.0	Simple motions	1	5	3	2
		1.1.2.0	Complex-coordinated motions	4	0	2	3
		1.2.0.0	Motor-static	0	0	1	1
		1.3.0.0	Speech	1	4	0	0
		2.0.0.0	Engram	2	3	1	3
		2.1.0.0	Short memory	4	4	4	4
		2.2.0.0	Long memory	1	1	1	1

/10

the specific stress of operator performance. For example, 0 corresponds to some optimum stress, and 5 to the maximum stress on the border of a breakdown in functioning.

The principle forms of specific stress involve intensity and tempo.

Intensity stress can be characterized by the force (intensity) needed to convert information from activation processes, or by the physical force of motor reactions.

Where the perception process is concerned, the zone above the operative difference threshold (separation of useful signal from noise), of the probability of the appearance of a given signal stronger than 0.7, and the greatest significance of the given signal among the other anticipated signals, is that of 0 intensity stress. At 5 the physical force of the signal corresponds to the zone near the difference threshold (the "zone of doubt"), and the operator evaluates the probability of the appearance of the signal subjectively as "no signal was heard for all practical purposes." Significance is considered to be negligible.

Intensity stress is measured by the force loading with respect to motion. /11 Five is the limit of force potentialities of the given motion, or of the magnitude of the load, excluding the muscular-joint sense, and thereby causing lack of coordination of the motor act.

Tempo stress is associated with the frequency of delivery of information, and, consequently, with the rate at which the information is processed. The original magnitude can be the number of signals perceived, the number of solutions, or the number of motor reactions in unit time. Five is understood to mean tempos at which misses, or errors, are 50 percent because of lack of time.

Classification of nonspecific stress (Table 2) is listed in a hierarchical system similar to that used in Table 1. Stress (weight) is evaluated in conventional units using the following scale: 0 - optimum; 1-2 - slight stress; 3-4 - extremal stress (included are the conventional reserve psychic and physiological mechanisms, man applying volitional forces, regulation of the cardio-vascular system is changed, and the like); 5 - super-extremal (included are the last of the reserve mechanisms, and the posing of a threat to health). The evaluation

on this scale of each of the more general indices in the hierarchical system adopted will depend on the selection of the maximum evaluations from among the set of special indices.

TABLE 2. CLASSIFICATION OF NONSPECIFIC PERFORMANCE STRESS

Hierarchical number of characteristic	Characteristic of stress	Weight of stress, units P	AD	AM	C
1	2	3	4	5	6
1.0.0.0	Attributable to performance process	4	1	2	2
1.1.0.0	Information-psychological	4	4	2	2
1.1.1.0	Activation	1	1	0	3
1.1.2.0	Operational	4	4	2	1
1.2.0.0	Energy-force	3	2	3	3
1.2.1.0	Energy expenditures	3	2	3	3
1.2.2.0	Muscular work	3	0	4	2
1.3.0.0	Strain on the vegetative physiological systems	4	1	2	1
2.0.0.0	Attributable to performance conditions	4	2	2	1
2.1.0.0	Attributable to psychophysiological conditions	4	2	1	2
2.1.1.0	Motivational	1	1	2	1
2.1.1.1	Adjusting	1	1	2	1
2.1.1.2	Effectiveness	1	1	1	1
2.1.2.0	Responsibility for achievement of work goals and the condition of people	3	3	1	2
2.1.3.0	Personal danger	4	0	0	2
2.2.0.0	Attributable to the limitation on rest between work cycles	1	1	1	0
2.2.1.0	Sleep limitation	2	2	2	1
2.2.2.0	Active rest	0	0	0	0
2.3.0.0	Limitation on requirements not connected directly with the work processes	2	1	1	0

Hierarchical number of characteristic	Characteristic of stress	Weight of stress, units P	AD	AM	C
1	2	3	4	5	6
2.4.0.0	Attributable to physical and chemical conditions	3	0	1	0
2.4.1.0	Microclimatic	2	1	2	0
2.4.1.1	Composition of the gas medium	1	0	1	0
2.4.1.2	Temperature	2	1	2	0
2.4.2.0	Chemical	0	0	0	0
2.4.2.1	Food (water) factors	0	0	0	1
2.4.2.2	Toxic impurities	0	0	1	0
2.4.3.0	Physical	4	0	0	1
2.4.3.1	Gravitational	4	0	0	1
2.4.3.2	Mechanical	3	0	0	1
2.4.3.3	Barometric	1	0	0	0
2.4.3.4	Radiation	0	1	0	0
2.4.3.5	Magnetic	0	0	0	0

/13

Most of the stress characteristics listed in Table 2 are clear enough, but there are certain of them in need of explanation.

Activation stress reflects those volitional forces that must be applied by the operator during the performance process in order to maintain the necessary attention level. This latter depends primarily on the diversity of situations, or signals, to which the operator should react, on the diversity and complexity of decisions and actions. Five can be taken as the diversity close to zero, leading to the dreamy state (extreme monotony of performance), or, conversely, can be taken as extreme diversity, leading to so rapid a shift in attention as to excite a type of emotional stress that is destructive of the optimal performance structure.

Operational stress can be used to make an integral evaluation of the outcome of the operation at a pragmatic level. It depends on the total number of signals perceived, decisions made, actions with their tempos taken into consid-

eration, degrees of attention stress, and the like. This is a practical way of expressing the particular degree of fatigue involved.

The adjusting motivation stress characterizes the initial (fixed setting) interest of the operator in the particular type of performance in terms of different motives: 5 is no interest (something that requires strong volitional forces), and 0 is the highest degree of interest.

Effectiveness stress determines the degree of positive attitude toward the performance engaged in, and depends on the results of this performance (positive confirmation). Stress will increase with lack of success in achieving the goal.

2. Ways to Obtain the Original Information Needed to Describe Performance

The following are ways to obtain needed information:

1. extract the information from technical and operational documents;
2. engineering-psychological survey of equipment; /14
3. observation of the progress of the job process and of operator behavior;
4. meeting with operator (operators);
5. operator's own report while performing;
6. questioning and expert evaluation;
7. time study;
8. objective recording and measurement of components of the job process (motion picture films of the eye movement and of instrument readings, recording of movements of control organs and measurements of force of action taken, tape recording of messages, etc.);
9. recording of indices of certain of the physiological functions;
10. recording and analysis of errors in the work done by the operator;
11. measurement of indices of environmental factors;
12. laboratory and natural experimentation.

Extracting the Information from Documents

Documents, from the standpoint of performance analysis, can be broken down into three groups, characterizing:

the content and organization of the job performance, control system devices, and special features of the environment;

summaries of performance;

individual characteristics of operators.

The first group includes a description of the objects of the technique, operating manuals for the objects, instructions for training operators, instructions for the later work of the operators, and the like. Study of these documents results in familiarity with the specifics of vocation performance, and its tasks, with efficiency criteria, with the installation at the work site, and with the organization of interaction between operators, as well as between the operator and the environment taken into consideration.

Then, the basic operations (emergency operations, those associated with a time deficit, and the like) for the various levels are distinguished on the basis of the information extracted and their psychophysiological content tentatively evaluated. Individual operation graph-algorithms characterizing the complexity of the performance are formulated [10].

The documents in this group also will yield information on operator performance conditions, something that must be known in order to make an approximate evaluation of nonspecific stress [5, 15].

Instructions for the work to be done will provide the possibility for making an approximate evaluation of the degree of specific stress placed on performance in terms of the rate at which the work must be done, the accuracy with which operations must be performed, and the like. /15

The second group includes the logs for accounting for training, books for recording dependability of parts, check documents, and the like. This material is one of the sources from which data needed to analyze errors made by specialists is obtained. Moreover, this material can provide information needed to evaluate the personal qualities and professional level of skill of specific personnel. From this point of view, analysis of individual documents, (flight, and diving logs, and the like), as well as of medical documentation, is of interest.

The third group includes documents certifying specialists, service characteristics, and the like. This material contains data for evaluating personal qualities, primarily. Unfortunately, the terminology used to describe these qualities in terms of characteristics is not yet sufficiently standardized, and this makes an unambiguous analysis of the documents listed difficult.

Engineering-psychological Survey of Equipment

The first thing that must be done when surveying equipment is to obtain preliminary information on the conditions under which the performance will take place and thus influence nonspecific stress. Included are microclimate (temperature, relative humidity, air velocity, barometric pressure), gas composition of the air, harmful impurities in the atmosphere (exhaust gases, bacterial contamination, and the like), the physical factors of the environment (acoustic noise, vibration, illumination, radiation, and the like).

Study of equipment should anticipate obtaining:

concise information on the purpose and design of the basic systems handled by the operator, and their characteristics, from the standpoint of efficient achievement of the goal;

data on the purpose, operating principles, and design features of indicating and monitoring instruments, as well as of control organs. Methods used to code signals, information reflection principles, evaluation of correspondence between equipment and the basic engineering-psychological requirements in particular are distinguished;

the scheme for locating the basic instruments and control organs, data on attainability and review areas, and the like.

Observation of the Progress of the Job Process and of Operator Behavior /16

Observation of the progress of the job process should provide for the obtaining of such information as:

characteristics of information inputs for the number of information channels, dynamics of the timed arrival of information;

the time characteristic of the work: continuous, or discrete when time is short, when the condition is one of anticipation;

characteristics of verbal communications (information and orders) given the operator: sources, types of channels (directly by voice, through a speaking tube, by relay, classification of communications by type of response reactions, and others);

characteristics of non-verbal audible signals: semantics, physical parameters, presence of interference, or noise;

characteristics of visual information: semantics, intensity, duration, and color of signals, brightness and color contrast, rate of arrival of information, interference;

data on interaction of analyzers: discrimination of basic analyzer, dynamics of cutting in various analyzers, degree to which they are loaded, and the like;

data on the functioning of the support-motor apparatus: the work posture and the posture during the "active rest" period, nature of job movements (direction of movement, amplitude, tempo, applied forces);

characteristics of operative and long-time memory: how much information must be remembered for short and long periods of time in order to perform the work, how stored (in the mind, recorded on paper, other forms of recording), nature of stored material (symbols, figures, philologic-logic, and the like);

characteristics of the processes involved in making decisions: preferred methods for man to use in processing information (reactions of selection, logic, counting operations, heuristic methods, types and degrees of preparation of information for making decisions, time characteristics of degrees of information preparation for the decision);

characteristics of errors;

data on volitional and emotional stress: frequency of occurrence of situations requiring strong volitional forces, work under unfavorable conditions when distractions are present, when danger exists, and the like; principles and /17 degree of emotional stress (danger, heavy responsibility, lack of time, ambiguous information).

It is desirable to make observations of work processes that have a prepared flow diagram of the algorithm for carrying out the most important operations (see below).

One of the results of the observation should be the development of the structure of the control framework within which the man is working. The following figure is an example of the flows of information that take place within the framework of piloting an aircraft.

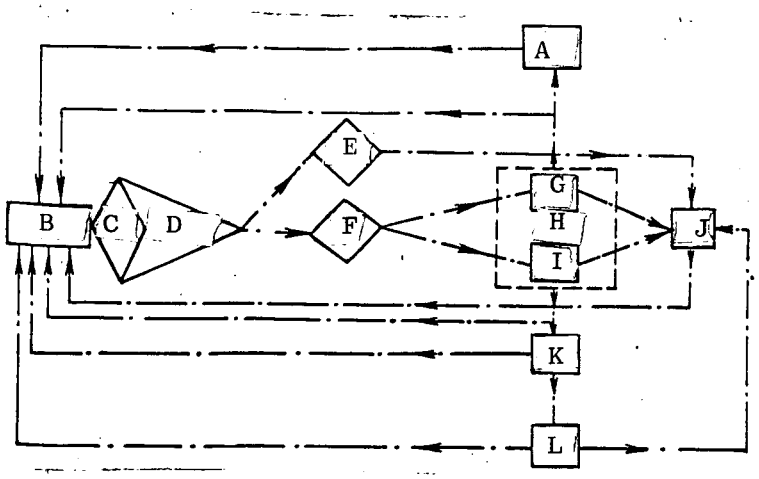

Diagram of the interconnection of flows of information in an aircraft control system (piloting). A - distant-reading gyromagnetic compass; B - afferent system; C - central nervous system; D - efferent system; E - throttle; F - stick; G - bank indicator; H - master attitude indicator; I - pitch indicator; J - aircraft longitudinal displacement rate indicator; K - vertical speed indicator; L - altimeter.

Observation of operator behavior as he does his job makes it possible to obtain information on the specific and nonspecific stresses involved in his performance on the one hand, and on the level of professional skill, and personal qualities of the operator, on the other.

Meeting with Operator /18

Meeting with the operator makes it possible to obtain additional information on the organization of the job, and on his subjective reflection of the operations.

The difficulty that can arise during the meeting with respect to the first of these goals is associated with the need to differentiate from the preconceived notion the operator may have in evaluating job difficulties, or other persons about whom he will be asked to talk.

The achievement of the second goal of the meeting must be based on remembering that many of the job operations, and their elements, may not be reflected consciously, or they may be reflected in distorted form. The "interviewlogy" rule must be observed in order to reduce the probability of obtaining false information [27].

Operator's Own Report while Performing

This method is suited to the analysis of that part of the performance that flows as a mental process based on an active reflection in the consciousness. But in this case the report on the operations performed by the specialist does not, intrinsically, upset the psychophysiological structure of the performance. For example, attempts to use radio reporting to determine the time the pilot becomes aware of instrument readings in flight proved to hold little promise. The results

were very greatly exaggerated because the pilot performs many of the control operations automatically, without transmitting instrument readings in the voice code.

The running report ("thinking aloud") method still has no substitute for analyzing the internal structure of the thought processes. Tape recorders usually are used. The value of the method has proven itself in practice more than once.

Questioning and Expert Evaluation

Questioning can be conducted to obtain a "free response," or a "selected response." In the case of the former, the questions are formulated in such a way that the operator concerned can write any response in arbitrary form. In the latter case, the operator, after each question is given a list of possible responses, and he must select one and underline it.

The "free response" queries have the advantage that they call for no initiative on the part of the subject. The shortcomings are the great deal of time lost in filling in, in mistakes connected with lack of understanding of the sense of the question, or with forgetting possible responses. /19

Questions of the "selected response" type are filled in much more rapidly and limit the possibility of obtaining answers not anticipated by the experimenter. They also have the advantage of being easy to submit to statistical processing later on. Questions of different types sometimes are combined in one questioning session.

Expert evaluation is questioning by very experienced specialists. Expert evaluations can be used when analyzing job performance, particularly to determine the degree of specific stress. A convenient scale to use for the evaluation is one in which 0 means there is practically no stress, 1 very slight stress, 2 moderate, 3 considerable, 4 great, and 5 very great stress.

Time Study

Time study results in determining the duration of individual job operations, the frequency with which they are repeated, the intensity of the job process, and the length of pauses between individual operations.

The chief prerequisite for the proper conduct of a time study is to separate the operations. Not until the level of quantization of the job process has been

clearly established and the list of operations recorded at that level has been compiled can the time study begin. The methods and techniques used to measure time can range from the use of a stop watch started by the observer, to oscillograph recordings accurate to within milliseconds [1, 4].

Objective Recording and Measurement of Components of the Job Process

A great volume of information on the number of operations involved in a job performance, the connection between those operations, their time characteristics, and stress, can be obtained by recording:

the specialist's eye movements;

movements of hands and feet;

vocal communications.

Recording of eye movements, and determination of the time the eyes become /20
fixed on their target, can be accomplished in several ways. The most accurate way is to use sensors fastened directly to the eyeball [12]. The accuracy of this method in determining the difference in looking in two directions is high (1^{o}). However, the complexity of the recording system and the time required for the recording (2 to 3 minutes) reduces its practical value.

Less accurate (up to 6^{o}), but much simpler and convenient in practice is the method of taking synchronized motion pictures of the eyes and of the indication field, an instrument panel, for example, followed by frame by frame visual interpretation of the direction of gaze using standards [14].

Potentiometer sensors, followed by amplification of signals, and oscillograph recording, usually are used to record the movements of hands and feet. There are other recording methods that can be used [4, 5, 15, 16].

The recording of vocal communications while performing a job process has two features: first, it is necessary to record the communications between a minimum of two persons, as a rule, and, second, an accurate time "tie" of the phases to the other processes and operations is required. The first problem is resolved by several parallel connected throat microphones, or a multichannel magnetic recording. The second can be solved by using parallel recorded audiograms (by converting sound into mechanical oscillations) on an oscillograph tape [11], or by installing a special plotting attachment on a tape recorder. The attach-

ment is a graphite scriber with electromagnetic control. The times of beginning and end of utterance of words is noted on the back side of the magnetic tape. This makes for quite accurate measurement of the length of a section of tape corresponding to the predetermined message, and then, knowing the rate at which the tape has moved, to calculate the time.

Recording Indices of Certain of the Physiological Functions

The reaction of the body's physiological systems to the job performance reflects, albeit not entirely uniquely, the "physiological cost" of the work; that is, the nonspecific stress, including emotional stress. The principal indices of the physiological functions are the electrocardiogram, the electromyogram, the /21
arterial blood pressure, respiration, and the galvanic skin reflex. The recordings can be made by distant-reading methods known to physiology [1, 4, 8].

The greatest difficulties are encountered in diagnosing the condition of the body, and not in the recording itself. There are a number of diagnostic techniques for different degrees of automation.

The recording methods listed should be used as a complex. This does necessitate, however, synchronizing all the recording channels with respect to time, and then resorting to computer techniques to make the mathematical analysis.

Recording and Analysis of Errors in the Work Done by the Operator

Study of errors, and their causes, yields a wealth of material for evaluating specific and nonspecific stress, and in determining the most difficult of the operations. Analysis of errors detected is based on the principle of the exposure of a cause and effect relationship. An error is understood to mean that deviation (mistake) in the actions taken that can lead to a reduction in the efficiency of operation of the "man-machine" system.

Classification of Errors Made in the Job Performance Process [1]

A. According to external criteria for job operation accomplishment.

1. Drop out of elements of the job process (operation).

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[1] There is no strict and unique separation of the individual types of errors into various classes in the proposed classification. The authors, aware of this, nevertheless lean toward a logical strictness in the classification, hoping that the proposed variant will be useful from a didactic and practical point of view.

2. Appearance of additional (unanticipated) elements of the job cycle.

3. Disturbance in operation sequence.

4. Distortion in communications between signal (signals) and response (solution).

5. Deviation from the specified value for the parameter during sensometer actions: tracking, setting values on an instrument, and the like. /22

6. Excessive increase (over that allowed) in the time for carrying out the action.

7. Excessive reduction in the time for carrying out the action.

B. According to the psychophysiological nature.

1. Type of operation (process) on a psychophysiological level where a mistake has been made: perception, remembering, muscular, and the like.

2. Place of the mistake in the psychophysiological structure of the action taken: during the retention in the operative memory of the intermediate result in the process of making a decision, in a logic operation, and the like;

3. Nature of motivation: unintentional errors when attitude toward work done was positive, or negative, intentional (planned) errors.

4. Nature of attention: excessive, or insufficient, concentration; dislocation in switching structure, and the like.

C. Because of specific stress.

1. Great, intense stress: perception when noise is present; excessive or too low a load on the control organ; signal probability low, and the like.

2. High stress rate attributable to lack of time, or to very occasional signal delivery.

D. Because of the functional conditions of the operator (nonspecific stress).

1. When body condition is normal.

2. When there is a change in the body condition: fatigue, effect of extremal factors of the environment, emotional influences, influence of the pathological process.

E. General conditions reducing dependability of work performance.

1. Shortcomings in the organization of the work (distribution of functions between specialists, work standardization), in the motivation system (educational work, stimulants, penalties, and the like), in the regime for alternating

work and rest, in the content (quality) of the rest, in the formation of the skills of specialists. /23

2. Technique design faults: distribution of functions between man and machine; layouts of the equipment for reflecting information, and of the control organs; arrangements of the job site and the general arrangement of equipment.

3. Inadequacies resulting from sanitary and hygienic conditions.

4. Individual psychophysiological characteristics of the specialists (inadaquacies in vocation selection).

F. Because of the effect on performance efficiency.

1. Cause moderate disturbances, acceptable compensations.

2. Cause serious disturbances threatening interruption of work being done.

3. Lead to nonfulfillment of assignment.

Various assumptions as to the reasons for mistakes can be made when analyzing the mistakes. These reasons cannot be established directly. In this case additional examples and methods can be used [22].

Measurement of Indices of Environmental Factors

This group includes primarily conventional methods used to measure the physical and chemical factors of the environment (gas composition of the air, temperature, noise, illumination, and others).

Measurement of the characteristics of the psychological environment has a special place in the scheme. Observations, meetings, questioning, all of which already have been described, can be used for this purpose. Certain sociological measurement procedures also are desirable.

Laboratory and Natural Experimentation

Experimentation in the course of analyzing the psychophysiological features of job performance can be used to solve many problems which would yield solutions only with difficulty if all that was studied was the job process that takes place naturally. There are two groups of experiments that are based on real and modeled activity.

The following methods are used in experiments based on real activity. /24

The "job" method of studying a vocation. What this method amounts to in essence is that the experimenter has a vocation, and he then proceeds to provide it with characteristics based on his own feelings and impressions [32]. In many cases it is sufficient if the experimenter simply has a small set of operations that are the most specific of those in the job process under study.

The positive aspect of the method is that the subjective processes can be described in psychological categories immediately. However, this method can be used only for vocations that do not require lengthy training.

The additional tasks method. The degree of stress involved in the performance can be evaluated by giving the operator additional tasks, readily measurable, to perform. Discrete sensomotor reactions with a small signal alphabet, arithmetical problems, simple logic problems can be used for this purpose [9]. A high degree of motivation on the part of the specialist with respect to the additional tasks is the principal condition for successful conduct of an experiment such as this. It is desirable, therefore, to select tasks that are included in the structure of real performance.

The situational experiment. Situations that arise on rare occasions can be created artificially. Those situations causing psychic stress reactions have the greatest value. Practically speaking, it is only under these conditions that one can obtain dependable characteristics of the emotional and volitional qualities of specialists.

Models of stress situations should meet three conditions:

have a definite directivity, adequate to the tasks of the experiment;

the tests should perceive the stress situations subjectively as reality;

ethical standards should be observed.

The intention and accomplishment of the situations should be known only to a limited few if they are to be perceived as real. The secret should be kept after the experiment as well. A new form of model must be used for each subsequent experiment.

The following procedures can be used in experiments based on modeled performance.

Calculation of the individual components of the job process for detailed study. All the study methods used on modeling stands, in trainers, in simulators, and the like, are included in this group. /25

Investigation of specialists by analytical psychophysiological methods. These methods usually are used to select specialists after the individual qualities most important for the particular vocation have been exposed. However, these methods also can be used to determine the psychophysiological essence of the most difficult and important operations. The principle involved is the following. A group of the best and worst of the specialists is investigated, using methods, the psychophysiological essence of which is well known. Correlation with efficiency of performance is then determined. Methods indicating a high degree of correlation, obviously enough, reflect the psychophysiological essence of the most difficult operations in the performance under study.

3. Procedures for Operator Performance Synthesis, and Forms in which Performance Can be Described

The following not only will be a philological description, but also will be a formalized presentation of the dynamic structure of the performance and the obtaining of certain qualitative evaluations.

Operational-structural Description

The operational-structural description of a job process sometimes is called an algorithmic analysis. The former better reflects the essence of the matter because the description should include the characteristics, and those elements of job performance, that cannot be represented in the form of algorithms.

The essence of the operational-structural description is the expansion of the work process into qualitatively different components, determination of the logical interconnection between those components, the sequence in which they follow each other, and the calculations for a number of indices with a definite psychophysiological sense [6, 10].

It is desirable to reduce the job process to the operational-psychophysiological level. In this case the components of the process will be the operative units of information, the "logic conditions," and the elementary operations (operators). It is desirable to distinguish the following data for the operational-structural description:

the operation and its purpose; /26

characteristic of the start signal for the particular operation;

logic conditions under examination;

sources of information on the conditions under examination; signal code;

the logic connections between the original conditions (combinations);

solutions corresponding to the combinations of conditions;

form of realization of solution;

time characteristics;

psychophysiological characteristics of the operation.

The original data can be obtained by using the methods described in the preceding paragraphs.

Once the original data for describing the operational structure of the job process have been obtained, the next step is that of the description proper, using one of three methods.

The first method is a philological description of all operations, and of their sequence in terms of specific conditions.

Let us assume the operator must verify the working condition of the instrument with which he is to do the job before he starts actual work. This task can be carried out in the following manner:

(1) check to see if the instrument is, or is not, connected to the network; if it is, go on to step (3), if not;

(2) connect the instrument to the network;

(3) press the switch;

(4) check to see if the red light is on; if it is, go on to step (5); if not, go on to step (6);

(5) begin work;

(6) call the technician.

Steps 5 and 6 are final. At these steps the performance, in terms of the algorithm, is completed, depending on whether or not the preceding condition has been satisfied.

The second method involves the composition of the logic schemes for the algorithm in symbolic form, and the row entries.

The logic schemes are expressions composed of "operators" (operations) and logic conditions that follow after each other according to the logic of the process.

A numbered arrow ($\uparrow^3$) begins after each symbol for a logic condition and terminates at some other term of the algorithm ($\downarrow^3$). If necessary, in order to prevent operation of the algorithm from terminating after a series of elementary events, a special designation in the form of a so-called always false logical condition, ω, is introduced. Since this condition cannot be met, a term, indicated by an arrow, should operate after it in all cases. /27

The operation of the algorithm begins such that the left term of the scheme is in use. Then the term that should function after it is determined. If the first term was an "operator," the term in the scheme directly to the right should operate after it. If the first term was a logical condition, however, two variants are possible:

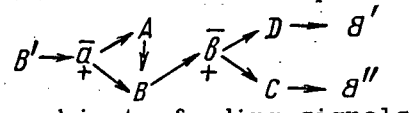
if the condition was satisfied, it is necessary to move on to the adjacent term to the right, without regard for the arrow;

if the condition was not satisfied, the arrow must be used and followed to the term to which it leads.

Let us compose a logical scheme for checking the operability of the instrument, and let us therefore introduce the following designations: instrument connected to the network - a; red light burning - b; connection of instrument to network - A; pressing the switch - D; commencement of work - C; call technician - E. Performance then can be written in the form of an algorithm as follows:

$$a\uparrow^1\downarrow^3 D\ b\uparrow^2 C\downarrow^1 A\ \omega\uparrow^3\downarrow^2 E.$$

The third method is a flow diagram (a kinemetric diagram). Here we have a visual presentation of all the links and interactions in the job process. Here is the flow diagram for the performance in the example under consideration



The symbol B' designates the objects feeding signals (logical conditions) to the algorithm input. The symbol β designates the objects to which the signals at the output of the algorithm are directed (β' is the technician, β'' the switch). The flow diagram makes it convenient to follow the progress of the process in each concrete case, and to gather data on the frequency of realization

of particular variants of the operations, on time parameters, and on mistakes occurring at some particular point in the structure.

Special entry forms, and additional symbols, must be used in more complicated cases [6, 10].

Some Quantitative Characteristics

/28

An operational-structural description of a work process provides psychophysiological indices that characterize quantitatively the controlling work done by the specialist.

The total number of different "operators" and logical conditions in the performance structure can, to some degree, characterize the degree of diversity of the work done by the specialist.

Knowing the number of "operators" and logical conditions, N_o and N_e, respectively, in the work cycle, the absolute frequency with which each "operator" and logical condition, q_o and q_e, respectively, is encountered, and the time required for the job process, T, we can calculate the mean dynamic intensity of the job process, or some particular stage of it

$$\bar{J} = \frac{N_o q_o + N_e q_e}{T}.$$

The evaluation of how stereotyped the work is, and how complex it is, as characterized by the number of logical operations, is of great importance, so far as the psychophysiological characteristics are concerned.

The stereotype characteristic of the job process is based on an analysis of the distribution of "operators" by groups. The more groups there are in the algorithm that cut in a continuous sequence of "operators," and the longer this sequence is, the more expressed is the stereotype component in the particular type of job performance.

The stereotype factor for the work process can be calculated through the formula

$$\beta = \bar{S}_{o_i} = \sum_{i=1}^{n} i P_{o_i},$$

where

S_{o_i} is the mean number of "operators" in a group (i=1, 2, 3, ..., n);

P_{o_i} is the frequency with which the i^{th} group is encountered in the algorithm.

The characteristic of the dynamic component of the work performance can be expressed by its logical complexity, if considered as a dynamic stereotype. This step should reflect the distribution of the logical conditions by groups analogous to the distribution of the "operators."

The following formula can be used to find the logical complexity factor for the work process /29

$$\gamma = \bar{S}_{l_i} = \sum_{i=1}^{n} i P_{l_i},$$

where

S_{l_i} is the mean number of logical conditions in the group ($i = 1,2,3,\ldots,n$);

P_{l_i} is the frequency with which the i^{th} group is encountered in the algorithm.

Analysis of the distribution of logical conditions by complexity groups leads to a way to characterize the degree of automation of the job performance. Automatism in the work of man is not the same as the work being stereotypical. Whereas being stereotypical means rigid determinacy of reactions, automatism means taking the corresponding action without consciously knowing about it, depending on the particular logical condition prevailing. Since automatism can be developed only for simple logical conditions, it can be assumed that the automatism coefficient will be expressed as the ratio of the probability of groups of one logical condition to the probability of all the other groups of logical conditions

$$\rho = \frac{P_{l_i}}{1 - P_{l_i}}.$$

The quantitative characteristics cited in this section are special indices reflecting the various psychophysiological properties of operator performance. Yet another set of similar measures has been proposed [10, 13, 21].

This raises the question of whether or not it is possible to obtain a single integral characteristic for the psychophysiological features of work performance. It would be extremely difficult to do so, because of the many facets of the properties involved in the work process. Definite values, based on informal considerations, can be given to individual, special, characteristics, and thus

derive an integral index. Yu. S. Perevoshchikov [24] has suggested one possible approach to obtaining such an index. His idea is to use a series of coefficients reflecting the diversity of the logical conditions, and the tempo and intensity stress.

4. Determination of Personal Qualities Most Corresponding to Vocation Performance

/30

The compilation of the vocation profile is followed by determination of personal qualities (functions) that will result in the accomplishment of each element (operation) of the job process. A scale of six system (0 to 5) then can be used to evaluate the following characteristics of the developed functions:

the degree of importance of each function in achieving the final effect when performing a concrete job operation;

duration of the load imposed by the function throughout the job process;

degree of load in the course of carrying out the individual job operation;

degree of complexity of realization of each function.

The role of each of the psychophysiological functions in ensuring accomplishment of a definite job operation must be known in order to obtain the first characteristic. For example, reading a meter is ensured by the functions of perception, attention, and memory.

Performing the operation can involve the predominant load, the space (or motion) perception function, or operational memory, depending on the special features of the controlling task, instrument design, its location on the console, nature of marking, lighting, and the like. The lead function is given a higher evaluation than all the other functions ensuring completion of the operation.

The second characteristic is determined by data from a time study of performance; in particular, by the time required to complete each job operation realized by some particular function. The total time the concrete function is required can be expressed as a percentage of the total time for the job process, and can be evaluated by scaling.

The third characteristic is based on the use of quantitative indices of the load imposed on the function. For example, the degree to which the memory capacity

is loaded can be characterized by the number of remembered and perceived operation units, logical thinking, the number of logical conditions taken into consideration in arriving at a decision, and the like.

Finally, the fourth characteristic is an expression of the degree of complexity of realization of the psychophysiological function in combination with the hygienic conditions of the operation, special features involved in organizing the work process, functional condition of the organism, and by the effects of other factors. Realization of the function of perception, for example, can be complicated by noise, signal interference, body fatigue, and other factors. /31

An example of the calculation of the professional significance of the psychophysiological functions is given in Table 3 (fragment).

TABLE 3. CALCULATION OF THE PROFESSIONAL SIGNIFICANCE OF PSYCHOPHYSIOLOGICAL FUNCTIONS FOR THE OPERATOR OF AN ELECTRONIC COMPUTER

Operation index	Psychophysiological function	Evaluation of the psychophysiological function in terms of				Mean evaluation of significance of function, scaled
		degree of importance for achieving final effect	degree of load during carrying out of job operation	duration of load	degree of complexity of realization	
1	2	3	4	5	6	7
O_{15}	Perception					
	motion	5	3	4	4	4.0
	space	3	3	4	3	3.3
	Attention					
	capacity	3	2	3	2	2.5
	concentration	4	2	3	3	3.0
	switchability	5	3	4	2	3.5
	Memory					
	capacity of operative memory	5	4	3	3	3.8
O_{16}	Psychomotor					
	simple dynamic action	5	1	1	1	2.0

/32

Operation index	Psychophysiological function	Evaluation of the psychophysiological function in terms of				Mean evaluation of significance of function, scaled
		degree of importance for achieving final effect	degree of load during carrying out of job operation	duration of load	degree of complexity of realization	
1	2	3	4	5	6	7
O_{19}	Perception					
	motion	4	3	4	2	3.3
	space	4	2	4	2	3.0
	Attention					
	capacity	4	3	2	2	2.8
	concentration	3	3	2	2	2.5
	switchability	5	4	2	4	3.8
	stability	4	2	2	4	3.0
	Memory					
	short-time	5	4	2	4	3.8
	Thinking					
	visual-operative	4	4	2	4	3.5
	Psychomotor					
	complex motor action	4	4	3	2	3.3

The mean estimate of the significance of each function in carrying out the individual job operation, and the job process as a whole, is determined by the data for the characteristics listed. This summary evaluation then becomes the basis for the construction of a range of all the psychophysiological functions by degree of their importance to the performance studied.

The ergonomic description of the performance is an important factor in solving any of the practical problems of ergonomics, psychology, and physiology of work, or of engineering psychology. The content and depth of the analysis, as well as the form of description, can change with the type of problem.

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CHAPTER 2

SOME METHODS OF ERGONOMIC ANALYSIS OF PERFORMANCE UNDER PRODUCTION CONDITIONS /35

Increase in labor productivity in industry is impossible without a composite approach to job and production processes, without the scientific organization of labor, called upon to solve problems associated with providing for maximum efficiency in the use of machinery and equipment, as well as with increasing the effectiveness of the human factor, the role of which in modern industry becomes more and more important. Therefore, knowledge of job performance, as well as of sociology, social and engineering psychology, concrete economics, and industrial physiology and hygiene, all are gaining in importance in solving problems of the scientific organization of labor. These sciences, and branches of science, are faced with the task of rational construction (planning) of job performance, of training, of the selection of personnel for vocations, and the creation of the best possible working conditions for labor [14, 25, 30].

Concrete types and forms of the scientific organization of labor are closely associated with the special features of technological processes, with the level of mechanization and automation of labor. What must be taken into consideration in the planning of job processes first, is whether or not it is possible for man to carry them out, and, second, the requirements stemming from the content of the production operations.

A distinction must be made between the general psychological and production meanings of the concept of "operation" [24, 25]. In its psychological sense, operation is understood to mean the method used to do the job, determined by the conditions under which that job will be done. We shall call operations such as these job operations, and it is these operations that are the main topic of ergonomic analysis.

The job posture and job motions must be distinguished in addition to the /36 job actions and production operations. Job motions are subject to psychological investigation as components of job performance, as well as to biomechanical analysis, since both are expressions of the motor activity of the human skeletal-muscle system.

We must make a detailed analysis of the type of vocation performance under investigation in order to solve problems concerned with rationalization of the job attitude and job motions. This usually is called vocation profiling, ergonomic analysis, of performance.

The ergonomic analysis methods in what follows are in part a modification of classic methods of vocation profiling, and in part newly developed.

Let us consider the following ergonomic analysis methods, and how they are used.

1. Questioning or interview methods. Questionnaires are used, and ways to draw up and use them are described.

2. Subjective observation methods. Methods for formulating schemes for observing the organization of the job site, and the job attitude, are pointed out.

3. Objective observation methods:

a method that utilizes measurements and analysis of the three-dimensional organization of the job site;

a method that makes a time study of the job attitude;

a method that studies the dynamics of capacity to do the job in terms of production indices, and in terms of time study data.

1. Questioning Methods

Questioning methods (Figure 1) have been widely used in modern scientific research work. The types of questions asked, how they are phrased, and their thrust, are highly important when these methods are used. Consequently, all questioning methods must satisfy the general requirements that:

the questions contain no words with double meanings;

the questions relate to some degree to the interests, experience, and skills of the person being questioned;

the questioning should not take too long (no more than 20 minutes);

brief, preliminary instructions (warm up), explaining the purposes and substance of the questioning are mandatory [16]. A friendly relationship with /37
the person being questioned is extremely useful during in-house questioning.

Correct statement of the questions by the investigator is highly important for the effective use of questioning methods. Ye. S. Kuz'min, A. L. Sventsitskiy,

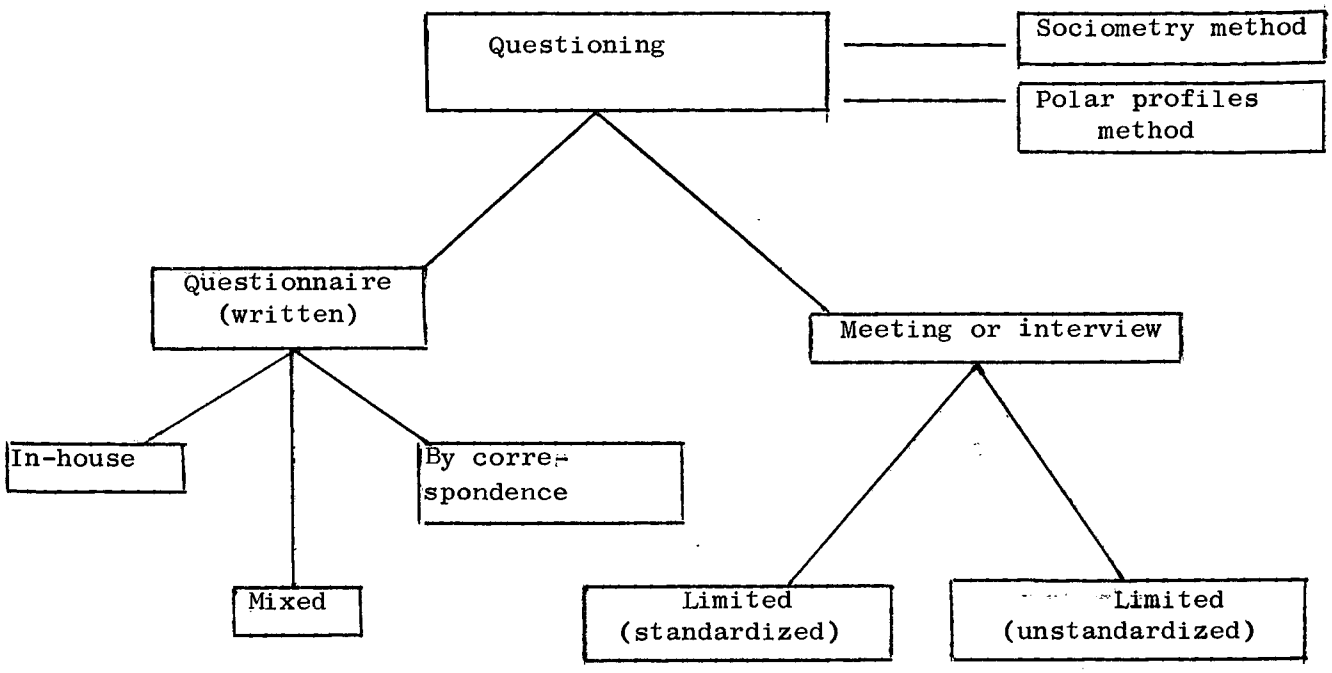


Figure 1. Questioning methods.

et al, of Leningrad University [16] have formulated the requirements that must be taken into consideration in compiling the questionnaire.

1. Questioning should not be used if the data can be obtained from other sources (such as the Labor and Wages Division, the Trade Union Committee, the Medical and Sanitation Section, simple observation).

2. The questions in the questionnaire should require no additional elucidations.

3. The questioning should begin with simple questions, gradually followed by more complicated ones.

4. Intimate, or particularly significant questions, should be placed in the middle, or at the end, of the questionnaire.

5. "Direct" or "indirect" questions should be used.

The meeting method is the most effective in solving such problems as those /38 associated with organization of the job site, or of its elements (lathes, console, armchair), or with study of the comfort of the job posture. This method permits refinement of answers to questions posed, explanation of questions causing difficulties of various types (terminological difficulties, for example), as well as the recording of remarks made by the person being queried that are beyond

the scope of the questions posed, but which are definitely of interest.

The questioning can have a time limit, and characteristic of such questioning is the advance preparation of the questions, as well as no time limit, characteristic of which is meeting freely with the person being queried. The investigator records only answers to questions asked during the meeting. This method is recommended when just a few workers are to be questioned.

The questions the investigator will ask usually are combined in questionnaires which are made up anew in each concrete case, with the specific features of the vocation under study taken into consideration. Prior to drafting the questionnaire, the investigator should spend some time observing the workers, or, better yet, himself learn the basic job operations. He then can draft the first version of the questionnaire and test it on a few test subjects.

Two types of questionnaires are given in what follows. The first was used to study the performance of dispatchers in composite power systems, and of dispatchers distributing tickets in stations. The purpose of the investigation was to develop the optimum variant of a work chair for the dispatcher. Consequently, the questions were directed at elucidating the subjective perception of the existing chair, and the wishes of those being questioned.

The second was used to investigate the work done by transformer coil winders in order to redesign the job site.

Questionnaire 1

1. Name and initials.
2. Age
3. Job
4. Length of service
5. Length of work day

Questions asked of dispatcher /39

1. Can you sit comfortably (yes, no)?
2. What makes you feel uncomfortable?
3. What part of your body hurts (back, small of the back, shoulders)?
4. Do your arms function comfortably (yes, no)?

5. Do you have to turn your seat (yes, no)?

6. Do you feel that it would be desirable for your chair to be on casters (yes, no)?

7. Does your back, small of your back, need support when you are working (yes, no)?

8. Do you need a tilting back (yes, no)?

9. Should your seat be flat, tilted backward, or forward?

10. Are elbow rests needed (yes, no)?

11. At what level should back support be (shoulder blades, shoulders, small of the back)?

12. What kind of a seat is needed (soft, medium, firm)?

13. How should it be upholstered (fabric, oil cloth, leatherette)?

Questionnaire 2

1. Name and intitials

2. Age

3. Job

4. Time worked as a winder

5. Length of work day

6. Number of machine

7. Type machine

8. Production norm per shift

9. Type of winding

Questions asked of winder

1. Can you work comfortably (yes, no)?

2. What makes you feel uncomfortable?

3. Which parts of your body tire the most when you are working (back, small of the back, shoulders, neck, arms, legs)?

4. What parts of your body ache (back, small of the back, shoulders, neck, arms, legs; during work, at the beginning, or after, work)?

5. Do you experience physical strain when you turn control levers, when you press the pedals (yes, no)?

6. Do your arms function comfortably (yes, no)?

7. Can you adjust your machine: height (yes, no), depth (yes, no), width (yes, no)?

8. Can you adjust the height of your stool (yes, no), shape (yes, no)? /40

9. Does your stool need a back (yes, no)?

10. At what level should the back support be (shoulder blades, shoulders, small of back)?

11. Is it desirable for your stool to have a tilting back (yes, no)?

12. What kind of a seat is needed (soft, medium, firm)?

13. How should it be upholstered (fabric, oil cloth, leatherette)?

14. Should the seat turn (yes, no)?

15. Does the stool need casters (yes, no); for both legs (yes, no); for left (yes, no)?

16. Do you need a foot rest (yes, no)?

17. How often do you have to stand up when you are working?

The effectiveness of questioning methods depends greatly on how well educated are those being investigated, on their vocational experience. Power system dispatchers, for example, are experienced, highly qualified specialists, working under very complex conditions. Prior to their having become dispatchers they had worked for stipulated periods of time in other jobs associated with the power industry. The responses they gave to questions when queried were exhaustive. Dispatchers distributing tickets in stations are mostly women with a middle, or an incomplete middle education. They have very little production experience, with the result that many questions are answered "I don't know."

So far as factory workers are concerned, they responded differently to general and specific questions. For example, their responses to the question "Can you work comfortably?" almost always were in the affirmative. Responses to specific questions were both positive and negative. Virtually all the workers complained of general fatigue, local aches and pains, remarked on inadequacies in the design of the machine, the stool, etc.

Questionnaires should be drafted according to job goals and tasks. Investigators are interested in all elements of the job site when it comes to redesigning the site; for example, the job area, the job chair, distance to additional equipment. But since the main object of the study is the man, all questions should reflect the interaction between man and the elements of the job site. Study of the job posture, changes in it, and the like, should be in the forefront.

As will be seen from the questionnaires included above, general questions /41 are asked first, "Can you work comfortably?" "Can you sit comfortably?" "What makes you feel uncomfortable?" responses to which provide the investigator with little in the way of information, but help to establish a rapport between the investigator and the one being queried. These are followed by questions concerning subjective perception of individual parameters of the job site, such as "Can you adjust the size of your console (height, depth, width)?" Then come questions concerned with the feelings of the worker. The parts of the body that ache, or get tired, must be noted. The wishes of the person being questioned are recorded in the next series of questions.

The questioning usually is done under natural working conditions for the subject at his job site, while he is working. However, the questioning can be done under laboratory conditions in the case of ergonomic research, using test specimens of parts, or an experimental test stand.

Any part can be used as the test specimen. The subject, checking the part out in operation, gives his evaluation of the part orally.

The experimental test stand is an adjustable mockup of a job site, or of one of its elements, such as a chair, for example, which can be given any linear and angular parameters.

The subject checks the variants of the job site, as set up on the test stand, and gives them a verbal characterization. Questions, and possible responses, are developed ahead of time. Particular attention during the questioning is given to evaluating the degree of convenience of the job site.

Data are processed statistically. The results of the processing are presented in the form of a report, and the data from own observations, and subjective comments made by the subject are differentiated. Moreover, the material described must be confirmed by data in the form of tables or graphs. Tables should include a particular index in terms of the total, in percentage (Table 1).

2. Subjective Observation Methods

Observations can be objective, or subjective, depending on the method used.

A subjective observation is one in which working conditions and processes are observed without using special devices or instruments. Its usual purpose /42

is that of serving as a preliminary orientation for the researcher. This type of observation usually should be preceded by other methods of vocation profiling, or combined with them, with an inquiry or with a "job" method, for example. Subjective observation can be selective and systematic, inclusive, and noninclusive, controlled and uncontrolled.

TABLE 1. RESULTS OF THE QUESTIONING OF THE COIL WINDER

Questions	Answers, %		
	Yes	No	Don't know
1. Can you adjust the size of your machine: height, depth, width	80.0	17.5	2.5
2. Can you adjust the size of your stool	84.2	15.8	
3. Does the stool need a back	25.0	65.0	10.0
4. Does the stool need a tilting back	2.7	73.0	24.3
5. Does the seat have to turn	87.0	13.0	
6. Are casters needed	2.5	95.0	2.5
7. Is a foot support needed	66.7	30.8	2.5
8. Are you improving your stool	25.7	74.3	
9. Do you use the foot support	38.0	62.0	

Of particular importance in vocation profiling investigations is the advance to and preparation of, the observation plan, the so-called controlled observation.

It is recommended that the noninclusive, controlled observation be combined with questioning. Just as in the case of questioning, here too a scheme is drawn up consisting of questions to which the investigator himself responds.

Presented in what follows are two schemes for observing the organization of a job site, of the job posture, and of the job movements. The first was drawn up to study the performance of dispatchers, the second that of the coil winder. The performance of the dispatchers was studied in order to develop ergonomic requirements for a chair, the performance of the coil winder in order to reorganize /43 the entire job site.

Observation Scheme 1

1. Specifics of the dispatcher's job in terms of use of the organs to do the job (hands, feet, vision, hearing).
2. Specifics of body position: fixed posture, mobility relative to the seat, to the console.
3. Angle of tilt of the trunk: negative (forward), erect, positive (back).
4. Height of support point for trunk (for back) above seat.
5. Height of console and angle of tilt of work panel.
6. Hands used (right, left, both).
7. Use of hands within reach zone: in depth (limit, close at hand), in width (to the right, to the left).
8. Correspondence of dimensions of console for hands: height (yes, no), depth (yes, no), width (yes, no).
9. Support points for hands (elbows, forearms).
10. Position of feet (right, left).
11. Correspondence of dimensions of console for the working zone of the feet: height (yes, no), width (yes, no).
12. What part of the seat acts as the support: front, middle, back.
13. Is rest outside the job zone possible.

Observation Scheme 2

1. Specifics of job in terms of use of organs (hands, feet, vision, hearing).
2. Specifics of body position: fixed posture, mobility relative to seat, to machine.
3. Angle of tilt of trunk: negative (forward), erect, positive (back).
4. Angle of tilt of head: negative, erect, positive.
5. Use of hands: constant (right, left, both), periodic (right, left, both).
6. Use of hands within reach zone: in depth (limit, close at hand), in width (to the right, to the left).
7. Correspondence between machine size and reach of hands: in height (yes, no), in depth (yes, no), in width (yes, no).
8. Which foot is used (right, left)?
9. Position of working foot when not in use: on the pedal, on the floor, on the base, unsupported. /44

10. Position of supporting foot: on the floor, on the base, on the pedal, unsupported.

11. Correspondence between machine size and reach of feet (yes, no).

12. Does the worker use a support for his feet (yes, no; for the right, left, both)?

13. Distance from the center of the armpit line to the mandrel (the lateral axis of the machine).

14. What part of the seat is the support: front, middle, rear?

15. Does the worker use improved stool (yes, no)?

The report of the results of the observations can be made in the form of a table, and should have appended to it instructions for its use. The table is compiled from observations (questioning of the worker is not precluded) made of the individual organization of the job site. The general technical names of all materials, attachments, and tools are listed in the "Item" column. For example:

tools: hammer, soldering iron, wire cutters, etc.;

attachments: template, vise jaws; as well as their shape (cylindrical, rectangular, round), etc.;

materials: spool (prefabricated, finished, manufactured) or interwinding insulation, end insulation, pigtails, pigtail fasteners, banding wire, rosin and tinning bath, additional materials, etc.

The other columns list the location of the materials and tools at the coil winder's job site.

The table can include an additional column for "Notes," where things not listed in the other columns can be entered, such as scattered, or carefully arranged, materials at the job site, whether surplus objects, materials, and other items are present, and the like (Tables 2 and 3).

The "Operation" column of Table 3 (fragment) must be used to distinguish and describe the operations investigated, as well as their elements, paying strict attention to the numbering and content at each point, thus providing the best correlation between data obtained and data from the time study for the corresponding operations. We shall use the list of operations involved in winding transformer coils as an example.

TABLE 2. ARRANGEMENT OF MATERIALS AND TOOLS AT THE COIL WINDER'S JOB SITE /45

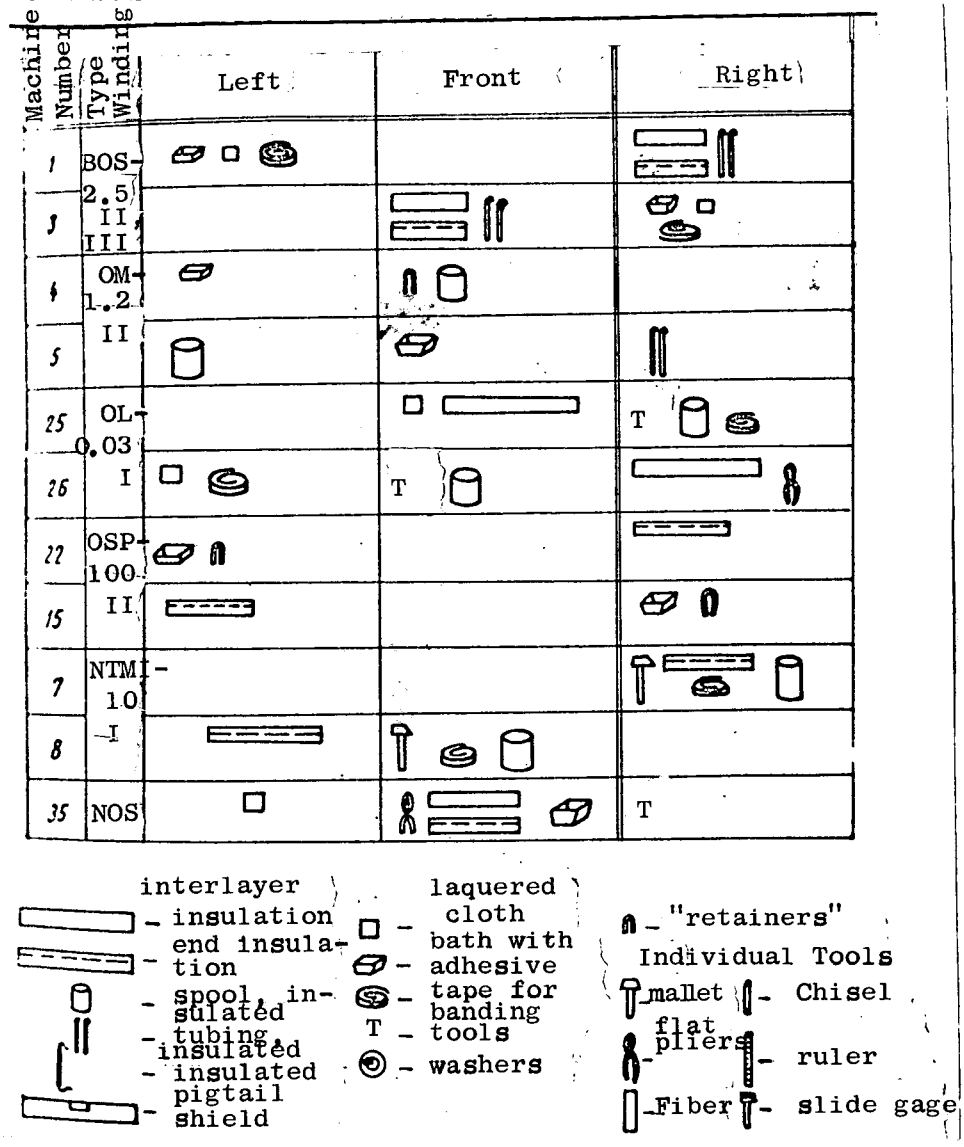


TABLE 3. THE TECHNOLOGICAL PROCESS OF WINDING /46

Operation	Right hand	Left hand	Note
1. Preparing pigtail	Take emery paper and clean off the insulation. Bind the soft pigtail. Dip the twisted wire in the rosin and tin. Pull on the sleeving. Bend the pigtail, hold it, and insulate with the lacquered cloth (suspended)	Pull the wire Help Supply the piece of lacquered cloth	The emery cloth is lying on the floor, making it necessary for the coil winder to bend over constantly.

Preparatory Operations

Preparation of the machine: installation of the wire (inspection, measurements), adjustment of wire tension, setting of the power feed and the power feed lever in the central position, assembly of the template and securing of it to the mandrel (the fastening for the first or second winding), setting of the counter in the zero position.

Execution Operations

1. Preparation of pigtail: pull the wire, clean it, insulate with sleeving or glass-lacquer cloth, twist and solder the winding wire to the pigtail, insulate the soldered joint.

2. Making the spool: winding the spool, assembly or fastening of the finished product (gluing, connecting, fasting with clamp, temporary technological binding, fastening with other material).

3. Winding the coil and placing the interlayer and end insulation: fasten the pigtail to the mandrel and lay the first turn of the first layer of the coil.

4. Bringing out the ends: put the "retainer" in place and fasten it, clean or clip the wire, solder or insulation, pass the pigtail through the loop (of the "retainers") and tighten the "retainer."

5. Banding and fastening.

6. Sealing the winding.

Monitoring Operations

Inspection. Measurements of outside and inside dimensions.

Analysis of the data listed in Tables 2 and 3 will lead to the conclusion /47
of rationality of the organization of the job site.

The rationality of the methods used to record answers is important when observations are combined with interrogation. The best approach is the one that envisages different versions of answers in the record (or in the observation scheme). Simple questions should draw unequivocal answers: yes, no, don't know. Responses that can be more complicated should be anticipated in advance, insofar as possible.

Schemes involving observations by several investigators working in tandem are taking on special significance because results can be summed and compared. However, in such cases the observers should receive clear instructions on how to conduct the observations and record the results.

The experimenter should bear in mind the fact that questionnaires, inquiries, and observation schemes are document type materials. They must be retained until the research is completed. Schemes must be carried out accurately, handwriting must be legible. Each sheet should carry the date of the investigation, the name of the investigator, and, in so far as possible, inquiry data on the subject - sex, age, vocation, vocational qualifications, The first, middle and last names of the subject are entered on the questionnaire only with his acquiescence.

3. Objective Observation Methods

Objective (instrumental) observation methods postulate the use of difference instruments and apparatus to obtain objective, quantitative characteristics of the process under investigation.

Objective observation methods include:

measurement of various characteristics of the production environment (illumination, noise, vibration, and the like);

metric measurements;

time study;

measurement of physiological indices (pulse, respiration, EKG, etc.);

measurement of psychological characteristics.

The first, and the last two methods require the use of rather complicated instrumentation. The use of the second and third methods have no particular limitations.

Since we here are considering methods of making an ergonomic analysis of activity in industry for the most part, we shall dwell in detail only on the metric measurements and time study. These methods can be used, in particular, to evaluate /48 the organization of the job site and working conditions in the section investigated.

Methods for Measuring the Parameters of the Job Site

Data on the dimensions of the production space of its individual elements, on the location of windows, doors, and data on the overall dimensions of equip-

ment, of job sites, and the like, can play a significant role in answering questions concerned with increasing the productivity of labor. These data can be used in designing new equipment, as well as in rebuilding equipment. Let us pause to consider the use of metric data for rebuilding job sites.

The three-dimensional organization of the job site has a great deal to do with the nature and quality of job movements, job posture, the nature of sensomotor activity, and the like. The development of the three-dimensional organization of the job site therefore is one of the initial stages of vocation profiling research.

First of all, let us establish what it is we understand the expressions "job site" and "three-dimensional organization of the job site" to mean.

The job site is understood to be that part of the production section directly associated with the accomplishment of the production process by the worker. Located here is the machine for concrete production operations, accessories having to do with some particular job posture (stool, support for the legs, etc.), a place for billets, materials, tools, organized rigging, and finished products.

The three-dimensional organization of the job site is understood to mean the location of equipment, and of its elements, organized rigging, tools, etc., used regularly in the production process, relative to the working man. The organization of the job site determines the motor and sensory activity of the worker in space, and this depends on the mutual location and nature (direction, speed, etc.) of the displacement of the job site elements relative to the machine operator.

Planning of the job site should be based on consideration of anthropometric data on the workers who will be using the equipment. Because the optimal dimen- /49
sions of the working space will be selected on the basis of anthropometry data, all of the elements of the job site must be organized in accordance with the peculiarities of man's activity. The following general rules should be followed in planning the job site:

first, plan the whole, then the details;

first, plan the ideal, then the real variant, of the system;

take the overall requirements for the organization of the production process, equipment parameters, and man's capability, into consideration.

Concrete requirements for the organization of the sensory and motor zone of the machine operator must be taken into consideration during the detailed devel-

opment (reconstruction) of the job site. Movements should be smooth and continuous, and the shape of the motion trajectories should be curved, corresponding to the peculiarities of the human skeleton. The direction of motion of the hands should correspond to the direction of movement of the eyes (for example, if the guide carriage of the coil winding machine moves from left to right after switching, the switch lever should move in the same direction). The principal visible elements should be in the vertical, within a 40° angle (10° above the visual axis, and 30° below it), etc. [34].

A scheme for making an analysis of the three-dimensional organization of the job site during its reconstruction follows.

Scheme for Analyzing the Three-Dimensional Organization of the Job Site

1. Isolation of the principal types of sensory activity (visual, aural, visual-kinesthetic, etc.).

2. Isolation of the nature of the motor activity.

3. Three-dimensional determination of the zones of sensory activity (with their scalings).

4. Three-dimensional determination of zones of motor activity.

5. Drawing the sketch of the location of the principal pieces of equipment relative to the worker, with the principal sensory and motor zones outlined.

6. Drawing the sketches of the location of the auxiliary equipment relative to the working man.

7. Drawing the general sketch of the job site. /50

8. Analysis of the material obtained.

The work is done as follows;

The principal and ancillary types and zones of motor and sensory activity are determined by observing the actions of the working man. The principal position and posture of the worker then are developed by interrogation and subjective observations.

The worker's body usually is fixed with respect to the machine. For example, the position of the coil winder winding transformer coils on his machine is very

rigidly determined by the following three-dimensional parameters: floor level (the base from which the height is read), the face plate, which fixes the position of the worker in terms of the machine's frontal plane (the worker regulates its rotation with his left hand), and the vertical axis of the face plate, which coincides with the vertical axis of the rotating coil and determines the position of the worker with respect to the lateral plane (depth) of the machine (Figure 2).

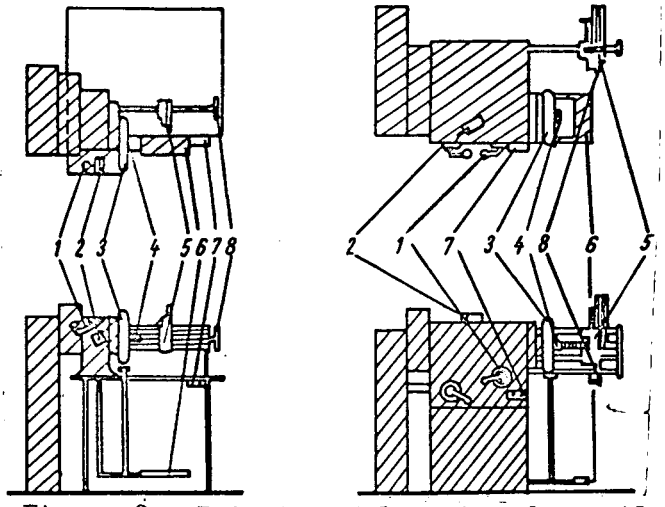


Figure 2. Principal elements of a coil winding machine.
1 - handle for switching direction of movement of carriage; 2 - spindle revolution counter; 3 - face plate; 4 - spindle; 5 - distribution carriage; 6 - pedal; 7 - machine start and stop buttons; 8 - carriage alignment handle.

Determination of the position of /51 the elements of the job site with respect to the worker must take into consideration the special features of body fixation when selecting the reading base. The reading base should be that element of the equipment determining the position of the man's body and his basic job postures.

Machinebuilding selects the extreme points of the overall dimensions, floor, lateral surface, frontal surface, axes, etc., as the reading base. For example, the right lateral surface of the face plate, its vertical axis, and the axis of rotation, are the reading base from which measurements of the coil winder's job site are taken.

Once the reading base is selected, measurements are taken, and the drawings showing the three-dimensional organization of the job site as a whole, and of its individual elements, are made.

The drawings made in connection with vocation profiling research have a somewhat different conceptual significance than is the case in machinebuilding, with the result that the methodologies used to make them differ somewhat from those used in machinebuilding drawing. The research drawings should provide information on:

the components of the job site for the "man-machine" system;

the overall dimensions[2] of the job site as a whole, and of the individual

[2] Overall dimensions is understood to mean the distance between the points farthest removed from the job site in height, width, and length.

elements of the equipment associated directly with the particular activity;

the three-dimensional and plane dimensional relationships of the components in the "man-machine" system, including the elements of the job site, the organization of the technical equipment, etc.

The external appearance of equipment, and the configuration of equipment elements, are of no interest at this point. Information about them can be obtained from photographs, drawings and the like.

Dimensions of main and auxiliary equipment for machines are shown in Figures 3 and 4.

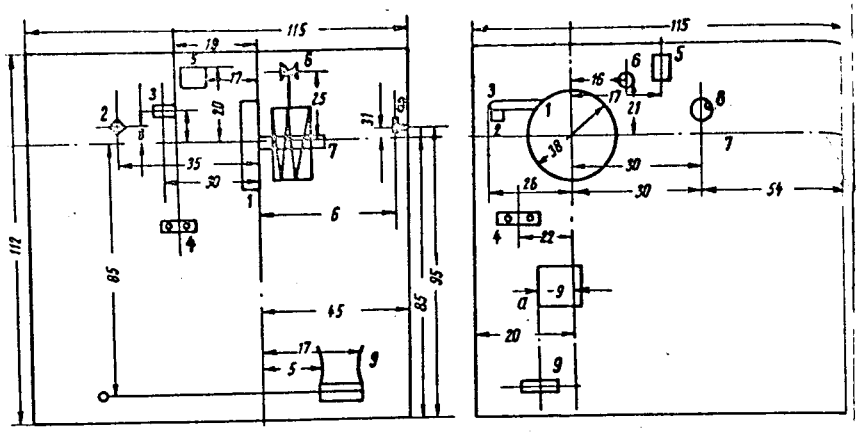


Figure 3. Three-dimensional location of principal elements of a coil winding machine (machine No. 17, for example).
1 - faceplate; 2 - counter; 3 - lever; 4 - starter; 5 - tin container; 6 - guide roller; 7 - shaft; 8 - handle; 9 - lever.

Sometimes the same operation is performed on machines with different geometric shapes and overall dimensions. In this case all of the machines present must be measured. The work is performed in the following sequence.

1. Elements that must be measured are determined (machine controls, indicators, for example).

2. The reading bases are selected.

3. Standard forms for making the measurements, and on which the arrows indi- /53 cate the elements to be measured, are prepared (see Figures 3 and 4).

4. The overall dimensions of the machine are measured and entered on the form.

5. The other dimensions of the job site are measured (their values are entered on the form).

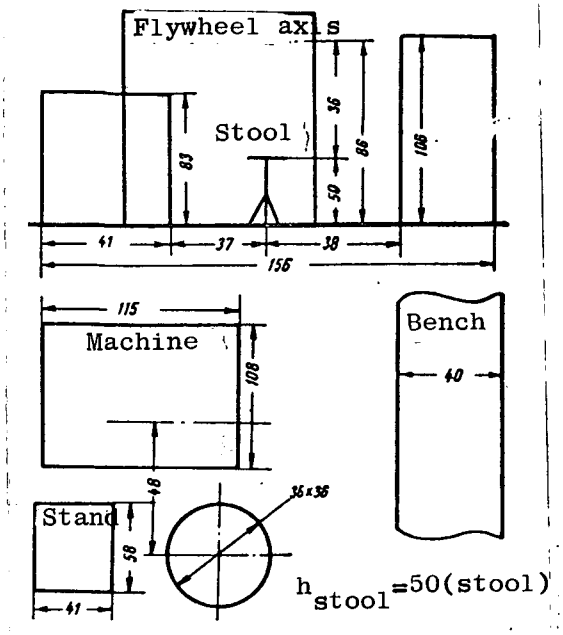


Figure 4. Three-dimensional organization and overall dimensions of main and auxiliary elements of the coil winder's job site (machine no. 18, for example).

All dimensions of the elements are shown on the form, and cases of noncorrespondence in the relative positions of elements too are entered on the form (for example, in Figure 3 the minus sign in front of dimension "a" means that the pedal is behind the vertical axis of the face plate, and not in front of it).

Measurements are listed in a common table (Table 4), then a composite sketch is drawn for each element (a sketch such as this for a spool is shown in Figure 5a). All machines on the reading base used are combined when drawing sketches such as these. Thus, the machines in the transformer shop are combined with respect to floor level and lateral surface of the face plate on the front projection, and with respect to floor level and the vertical axis of the face plate on the side projection. Since the height of the axis of the face plate from the floor will vary from 80 to 96 cm, the arithmetic mean of the height of the axis (89 cm) is taken, and the position of the worker is determined in accordance with existing anthropometric data on Russian women. Maximum and optimal reach zones are drawn in, in addition to the position of the body relative to the machine. The data in Table 4 are then used to plot points on the drawing obtained of the three-dimensional position of the corresponding control. Boundary points determine the operating zone of this control.

The pictures obtained illustrate the dispersal of the job elements in space, and the density of the points characterizes their preferred location.

The sketches make it possible to expose obvious noncorrespondence between the three-dimensional organization of the job site in use and human physiological and anthropometric characteristics. They are the preliminary materials on the three-dimensional organization of the job site, which then are analyzed from the

TABLE 4. DATA ON THE MEASUREMENTS OF THE JOB SITE FOR A COIL WINDER /54

Machine No.	Overall dimensions, mm			Height of stool, cm	Diameter of stool, cm	Distance between, cm				
	Machine	Stool	Bench			axis of stool and face plate	axis of stool and edge of stand	axis of face plate and seat	bench and axis of stool	edge of bench and axis of stool
1	128(x)	57	40							
	117(y)	80	85	59	40	49	34	36	42	173
	110(z)	40								
2	128	57	40							
	117	80	85	59	40	45	32	38	42	155
	119	40								
3	94	40	40							
	119	80	85	62	37	46	37	27	43	150
	104	57								

TABLE 4 (CONT'D)

Coordinates of measurement, cm							Length of mandrel, cm	Diameter of face plate, cm	Distance from lateral surface of face plate to edge of machine	Height of axis of face plate from floor, cm	(1)Direction of longitudinal axis of pedal (2)Working foot (3)Type support	(1)Shape and nature of movement of lever (2)Dependence of direction of movement of lever and carriage
counter	starter	flywheel	roller	spool	handle	pedal						
-16	48	49		-7	-16	28,43			77		1) →	
-6	-33	0	23	47	6	10	34	32		90	2)right	2)reverse
	-2		12	41	-19	21					3)frame	
-45	-18	45		-21	-25	13,43			77		1) →	1)
19	-5	0	20	31	10	10	27	34		93	2)left	2)reverse
	-2		20	10	-20	21					3)floor	
-19	5	com-		-15	-17	20,27			45		1) ↑	1)
-6	-24	bined	10	26	0	-5	32	27		87	2)right	2)direct
	-20	with carriage	14	21	-11	-13					3)reel	

Notes: (1) The point of intersection of the axis of the face plate and its right lateral surface is taken as the reading base.
(2) The positive direction of the reading is to the right and up from the base.
(3) The x axis is parallel to the front of the machine, the y axis is perpendicular to the floor, and the z axis is perpendicular to the xy plane.

This method of drawing the sketches greatly simplifies the analysis of the /55
organization of the job site, in particular development of the correspondence between existing and recommended zones, development of zones for the location of identical elements, something that is of particular importance in analyzing the activity of different types of equipment, etc.

Let us pause to consider the methods to use when applying anthropometric data to vocation profiling. Since anthroprometric characteristics are distinguished by ethnic, sex, and age variations, people have different average heights and body proportions. Therefore, prior to using the anthropometric data listed in some handbook, one must be persuaded that the data are for a homogeneous group, for the Russian adult male population, for example. In this case the best source is the data on the Russian population compiled by S. I. Uspenskiy and S. V. Yakubova [33].

Let us look into the methods for designing optimum and existing zones for the "average" person by the example of female transformer coil winders.

The position of the worker's body is depicted conventionally on the sketch for the main machine (see Figure 5). This is done as follows. Observations of how the coil winder does her job established the fact that her primary attention is directed to the coil she is winding. The quality of the coil is determined by sight and feel, so the worker assumes a posture relative to the machine such that the body's sagittal plane passes through the center of the longitudinal axis of the coil being wound. On the sketch this position is shown by construction of the frontal projection. Then the average height of the stool is determined, and the necessary dimensions of the worker's body are noted: height of eyes above seat; height of shoulder blades above seat; width of shoulders; length of body; height of elbows above seat.

The side view is drawn as follows. The mean distance from the vertical axis of the stool to the vertical axis of the face plate is determined. It is conventionally assumed in the case of a seated worker that the vertical axis of the spine passes through the middle of the stool. The dimensions used on the frontal projection sketch are used on this plan. Standard tables [33]are used to determine the length of forearm plus the wrist, the length of the arm extended forward and lowered, length of the femur, length of the leg, and of the raised arm, and then

the zones of maximum reach for arms and legs are constructed, as is the zone of optimum work. The zone is considered to be optimum if the arms are in the half bent position when work is being performed. /56

Should it be necessary to obtain orientation with respect to other than the "average" person, the zones of reach for tall, as well as short, persons are drawn in.

It should be noted that the proposed method is very approximate, giving an accuracy of the order of ± 2 cm, but its use under production conditions can be useful.

Figure 5 shows the three-dimensional arrangement of identical working parts of all machines relative to the worker (as dots and lines). At first glance it may seem that the dots are quite scattered, but the majority of them are within the limits of reach. However, if the time characteristics of the worker's movements associated with the production process as a whole, and the trajectories of these movements, are considered, the noncorrespondence in the location of some controls on the various machines, and their irrational locations is immediately apparent.

It is known that the most rapid movements are those of the arms away from the body, (ahead and to the side). When the arms are moving rapidly in the bent position, as is characteristic of our example, the range of their movements is decreased sharply to $\pm$10 to 15 cm in the vertical from the base of the work position and to $\pm$50 to 60 cm (for each arm) in the horizontal. Given this scope in movements, many of the dots in our pictures fall in a zone which is not optimum. The discovery of this fact is particularly important in determining the position of the handle for changing the direction in which the carriage moves and which must be used very frequently (see Figure 5b). In the majority of cases its placement is poor.

Included among the elements used quite frequently at the job site is the tinning bucket (see Figure 5a). Its location is poor, and in many cases is beyond the maximum reach zone.

The dispersion of the pushbuttons for starting the machine (see Figure 5c) is very great, with buttons located to the right (15 machines) and to the left (23

machines) of the worker, above, or below, the axis of the flywheel. This makes work inconvenient particularly when the worker moves from machine to machine.

The height of the shaft on which the coil being wound is located above the floor (see Figure 5d), and the length of this shaft, are of considerable interest in determining the posture of the woman winding the coil. This is the element /57 that is primary in determining the nature of the posture assumed by the coil winder, because it is on the height and length of this shaft that the working position of the coil depends, and this is continuously linked with the position of the coil winder's arms, the direction of her attention, convenience in use of the pedal, and the like. The height of the shaft varies from 80 to 96 cm, the length from 19 to 43 cm. If it is considered that the worker's left hand is used to regulate the speed at which the face plate is rotating, the position of which is quite rigidly fixed, we see that the length of the shaft has quite a bit of influence on the nature of the movement and the posture as a whole.

Both of the worker's hands are actively engaged when she is working. They hang at all times, without support. This results in a sense of fatigue by the end of the work day (71 percent of those queried), as well as aches (61.1 percent). The considerable effort exerted by the worker in securing the frame, and in banding, also is a cause of aching and fatigue. Vibration plays a particular role in causing aches.

The higher the longitudinal axis of the machine, the higher the worker must raise her hands, and the greater the static and dynamic loads on the muscles. In order to ease the strain on her arms the coil winder must raise her stool (average 57, maximum 69, minimum 40 cm) much higher than normal, but she still cannot reach an optimal position because her posture still is linked with the foot pedal (see Figure 5f).

Machine pedals are flat, rectangular in shape, of different sizes, and have different directions of the longitudinal axis. Pedal height varies from 5 to 20 cm. Design is such that even a long pedal can only be used by one foot because the longitudinal axis of the pedal does not coincide with the longitudinal axis of the stop usually recommended for pedals of this type. If the stool is too high the worker is forced to set the support for the other foot. Thus, 66.7 percent of the workers feel that a special foot support is needed.

The load on the worker's right and left legs is different. The right foot usually is the working foot (67 percent) and is on the pedal when winding. But in the case of coil winders working on machines with a short pedal the working foot often is the left one. In 42.1 percent of the working foot (right or left) is on the pedal while the coil is turning. Some coil winders take their foot off the pedal and put it on the floor (13.2 percent) or on the metal frame of the /59
machine (44.7 percent) when the motor is shut down.

The nonworking, or supporting, foot of most of the workers also is on the frame at the base of the machine (81.6 percent). Occasionally it is found on the floor, or on an empty reel (18.4 percent).

The presence of a flat pedal, and locating it near the forward surface of the machine, forces the worker to bend her knees and the talocrural joints at right angles at all times. It is a known fact that holding the legs at a 90^{o} angle for long periods of time results in rapid muscle fatigue. The most desirable position is when the bend is at an angle of approximately 105^{o}. This position of the leg joints can be achieved by locating the pedal so it is tilted at some predetermined angle to the horizontal plane. At the same time, the pedal must be within the depth of the machine, and not near its forward surface. Half of the workers queried complained of tired legs, and 21 percent of aching legs.

Let us now look at the turn counter (see Figure 5e). Its location is unsatisfactory. Visual perception of counter readings is particularly inconvenient. The optimum angle of vision should be 10^{o} above and 30^{o} below the axis of vision and encompass an angle of the order of 90^{o} in the horizontal in front of the worker [34]. The present location of the counters does not meet these requirements. When she is working, the coil winder's line of sight is directed at the rotating coil. Selection of the zone of optimum vision reveals that many of the counters are located outside this zone, serving to worsen working conditions for coil winders, slowing work tempos, breaking work rhythms, and increasing fatigue. In addition to the inconvenience in exercising visual monitoring of counter readings, the difficulties in zeroing the counter should be pointed out. This shows up in particular when analyzing the entire set of workers' movements.

What follows from what has been said is that the job sites for workers in /60
the transformer shop do not meet basic ergonomic requirements as to size, or

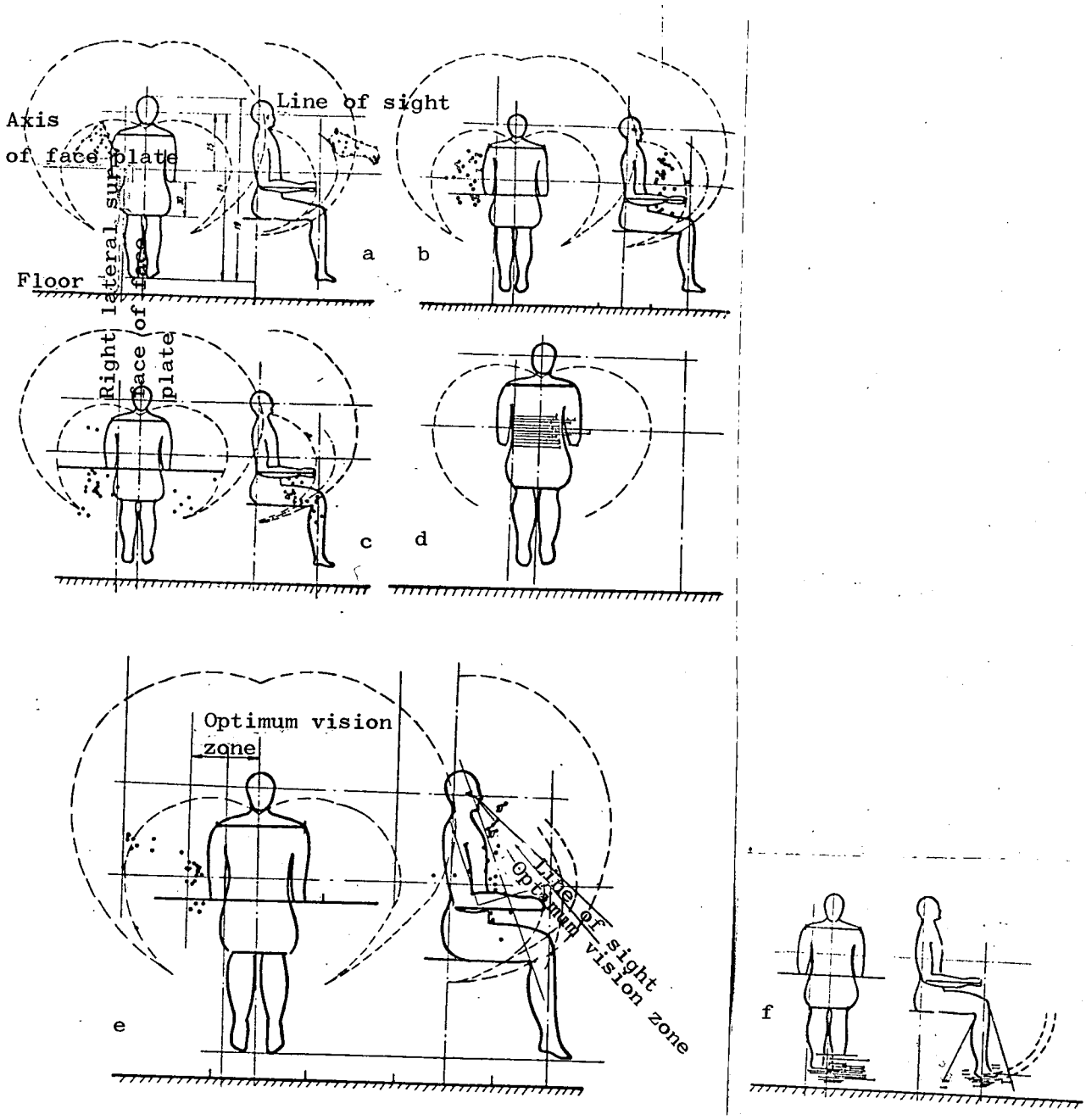


Figure 5. Three-dimensional arrangement of the working parts of the machine. a - bucket; b - handle; c - starter; d - coil axis; e - counter; f - pedal.

location of controls, and this reflects negatively on the well-being of workers and on the level of productivity. This is revealed in particular when the workers change from machine to machine. The chief cause of the sharp drop in the productivity of labor in this case must be considered to be the different ways in which machine work zones are organized (see Figures 2 - 6); that is, the differences in machine designs, the differences in locations of machine controls, and in the part being handled.

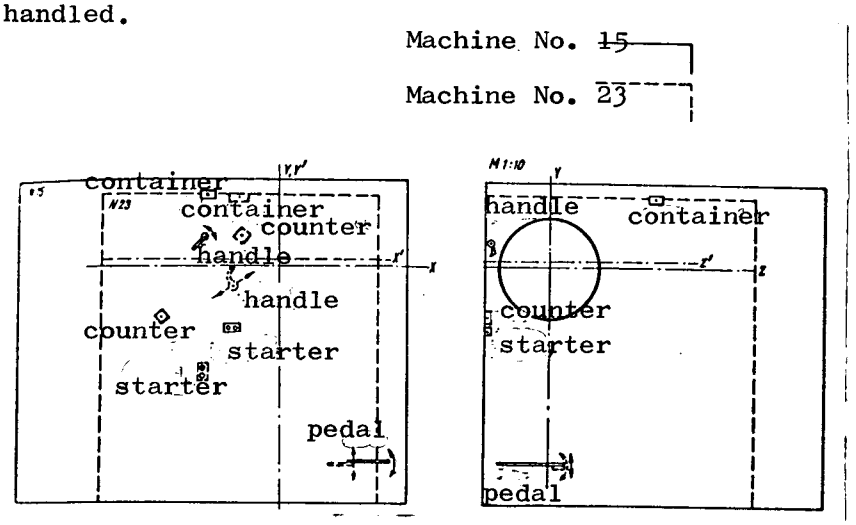


Figure 6. Three-dimensional location of elements of coil winding machines nos. 15, 23.

Machines numbers 15 and 23 (Figure 6), for example, have elements with the same names widely scattered in three dimensions, not only in the height at which located, but in the horizontal plane as well, and this leads to breaking down and reconstructing the stereotype of movements by the workers (direction, amplitude, and speed) that had been worked out, with the result that one observes a sharp drop in the productivity of labor.

Time Study

Time study is one of the objective observation methods. Time study usually is the name given to a method of recording changes with respect to time of certain parameters of a process with the aid of a stop watch, or clocks. Certain of the characteristics of the "man-work tool-environment" system can be investigated by this method in vocation profiling. The time study process can change with respect to time for each component of the system, as well as for their totality.

A time study makes it possible to determine the various time characteristics of the work process, with these characteristics then serving as the basis for establishing the distribution of time spent on various operations and in eliminating interference, the actual time spent on manufacturing units of production and on shift norms, time lost by actions indirectly affecting the work (leaving the work site, unavailability of materials, and the like), and for determining changes in human motor and sensory activities, as well as in the capacity to do work, in terms of time.

The time study can be used selectively when studying a vocation, as well as for taking photography of the working day as a whole, during various shifts, days of the week, and the like.

The time study should not influence the natural flow of the production process./61

As is the case for any method of making an objective observation, the time study method is preceded by preliminary preparation, including defining and studying production operations.

Operation by operation analysis of the production process is the basis for conducting an objective investigation of the time relationships in the production activity (frequency, length of action, the efficiency with which the working day is planned, pauses, idle time, and the like).

Operation by operation time study is used to determine the time spent on manufacturing production units, on performing various operations, as well as for distributing the time between the performing and auxiliary operations of the production process. Moreover, operation by operation time study data can be used to make a comparative analysis of the activity of workers so as to improve and organize production processes, and for discovering the rates of learning how to perform the different operations, in order to simplify and accelerate the learning process.

At least 5 to 7 measurements of each operation must be made during any oper- /62
ation by operation time study in order to obtain reliable mean data.

We have included, as an example, data from a time study made of the process involved in winding transformer coils (Table 5).

TABLE 5. SCHEME OF OPERATION BY OPERATION TIME STUDY

Operation	Time spent on operations, seconds Number of measurement								Mean time, seconds	Note
	1	2	3	4	5	6	7	8		
Preparatory										
Preparation of machine	5	3	6	4	4	4	3	7	4,5	
Performance										
Making the taps	10	5	7	4	6	6	5	4	6	
Making the coil form	7	15	14	13	18	7	15	12	12.6	Poor material
Winding the coil										
fastening the taps	4	8	7	15	15	20	11	7	11	
winding the first layer	30	28	33	21	31	32	25	35	30.6	
bringing out the tap ends										
placing the "attachment" & securing it	4	5	7	7	6	5	7	5	6	
solder or insulate the tap	3	2	4	3	4	7	2	3	3.5	
banding	24	35	35	37	32	34	30	30	32	
Monitoring										
Inspection	-	-	-	-	-	-	-	-	-	
Measurements	-	-	-	-	-	-	-	-	-	

Time Study of Job Posture

/63

One variant of the time study is chronography, involving a graphic method of recording time characteristics.

Chronography can be used under production conditions for characteristics of:

status and change in the motor activity of man as he works;

sensory activity in the job process.

Job motions (speed, direction, amplitude, and the like), job posture, number of times visual, aural, and tactile attention must be given to the object on which working, to the means whereby information is presented, and the like, all can be the objects of investigation by chronography.

Chronography of the job posture is the method that has been developed in the most detail, and has been tested as well.

When speaking of job performance, the term "job posture" can be used as a collective characteristic of the mutual arrangement of the parts of the body while performing job operations. There are many factors, biomechanical, physiological, psychological, and others, upon which the holding of a particular posture depend.

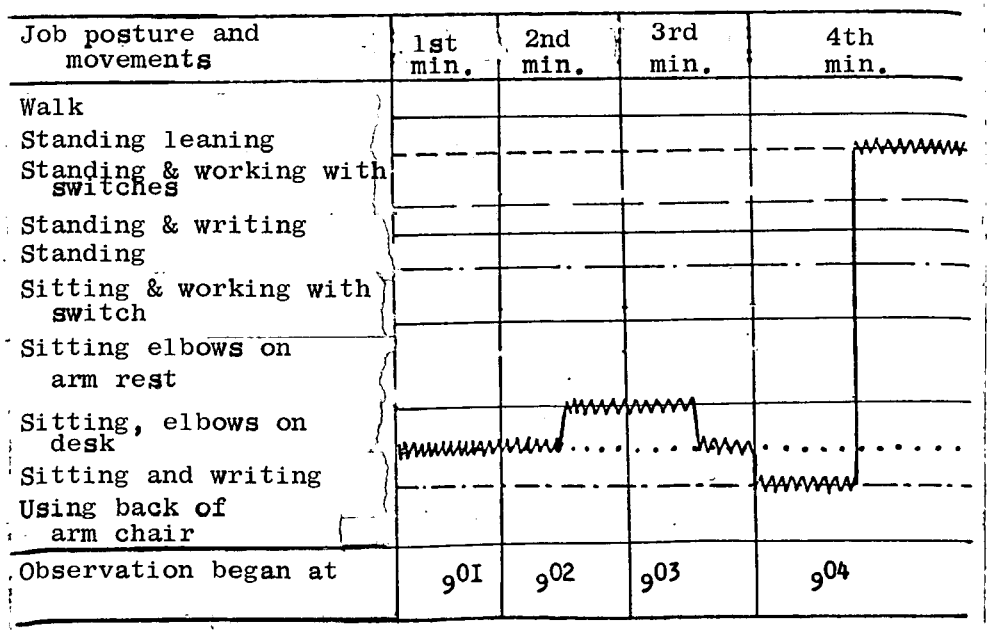
Just how comfortable the posture may be, and the possibility of developing fatigue as a result of holding the posture for a long period of time, depend on the position of the overall center of gravity of the human body over the support area, and on the magnitude of that area. Maintaining a definite posture at each given moment in time results from the static work of muscles to hold the body more or less immobile in terms of the requirements of definite job operations.

The compilation of the chronography scheme depends on the purpose and object of the investigation (Table 6).

There is a horizontal line, which can be shown graphically, or in various colors, for each recorded change in posture. Vertical lines divide the graph into one-minute segments. These segments, in turn, are divided into 15-second intervals. The time of commencement of observation is entered at the bottom of the table at each minute interval. When the dispatcher takes up a particular posture the time segment along the horizontal line corresponding to the particular change in posture is shaded.

TABLE 6. CHRONOGRAPHY OF JOB POSTURE AND MOVEMENTS OF A POWER SYSTEM DISPATCHER

/64



The total time a particular posture was held during the observation is calculated upon termination of chronographing. A table for each hour of work done by the dispatcher then is compiled. This latter is drawn up in five-minute intervals and lists the duration of a particular posture in fractions of a minute so it is possible to trace the dynamics of the movement. The duration of each posture over the hour is then calculated (in minutes). A summary table for the work shift then is compiled. Processing of the data obtained results in showing how the job postures are distributed in terms of time. Percentage relationships can be calculated.

This type of time study is quite effective when reconstructing job sites for dispatchers, operators, combine operators, drivers, and others. This method provides data on the movements of the body as a whole, develops the control organs used most frequently by the worker, and establishes how frequently man makes inconvenient and unnecessary movements.

The proposed chronographing scheme is standard in terms of the method used /65 to record the times changes in posture and movements take place. The set of recorded times can change with the tasks assigned the researcher.

Chronography of the dispatcher's work posture was made to establish how often, and in what percentage, he uses the various elements of the job site - switch, chair back and arm rests, etc.

Chronography of the coil winder's posture was made for a different purpose (Table 7). The posture assumed by the coil winder is rigidly fixed. Vision exerts primary control over performance. The worker cannot make drastic changes in her posture because if she does she cannot use the machine's controls.

Chronography of the job posture and movements of the coil winder can be used to recognize and record the times of the following:

basic job posture and time spent holding that posture;
times of change in posture, and their appropriateness;
primary and secondary movements, unnecessary movements;
duration of effect of vibration.

Chronography data on the coil winder's posture are an objective and graphic supplement to the materials obtained during the interrogation.

TABLE 7. CHRONOGRAPHY OF A COIL WINDER'S JOB POSTURE AND MOVEMENTS

Job posture and movements	1st minute	2nd minute	3rd minute
Walking			
Standing erect			
Standing bent over			
Sitting (preparatory operations)			
Sitting (executive operations)			
Sitting (break in wire)			
Sitting (rewind)			
Sitting, guiding wire with right hand			
Sitting, guiding wire with left hand			
Observation began at	9^{01}	9^{02}	9^{03}

Comparative data from the chronography of job postures of two coil winders are included by way of illustration (Tables 8, 9). Comparison of the postures of these coil winders, making different types of coils, uncovered the differences in the degree of stress imposed by the posture, in the causes of fatigue, and in the organization of the job site.

Chronography data on the coil winder's posture (see Table 8) show that the posture assumed by coil winders imposed great stress. The worker sits erect, her seat tilted forward slightly. She makes no unnecessary movements, only those that are standard for the job. Her eyes usually are lowered, concentrated on the coil. When each winding is completed she must check the turns on the counter, having shifted her glance to the counter from 5 to 10 times during the last minute of the winding process. She seldom glances to the side (the worker looks away from the part being made and looks straight ahead 7 times during the winding of one coil).

The worker stands only to replace the reel, or to get materials. She seldom has to walk for material, and very little time is required to replace the /66

TABLE 8. CHRONOGRAPHY OF COIL WINDER'S JOB POSTURE AND MOVEMENTS (TYPE COIL NOM-6-6000 II)

Coil No.	Time to wind one coil, min	Preparatory operations (setting), seconds	Executive operations (sitting) seconds					
			Winding I section of coil	Fastening	Winding II section of coil	Fastening	Rewinding wire	Break in wire
1	28	-	-	-	-	195	+15	-
2	26.5	197	162	190	442	172	175+	60+45
3	23.5	202	376	150	357	165	+45	-
4	27	140	295	187	377	187	50+15	97
5	23	180	352	187	340	105	30+20	100
6	27	245	440	217	370	165	75+5	-
7	23	225	357	175	292	155	60+40	-
8	24	262	337	160	255	160	20+30	60
9	20	205	255	135	395	145	46+20	70
10	27	195	445	210	355	175	80+15	-
11	27	194	336	157	382	180	50+	-
12	24	320	337	135	329	150	50+15	-
13	24	194	317	180	408	142	74+30	-
Mean		197	308	160	331	161	22 times	6 times

TABLE 8 (CONT'D)

Monitor operations	Adjust reel by hand	Adjust reel with foot	Standing erect, seconds	Standing stooped, seconds	Walking, seconds	Changing reels	Leaving job site for materials	Other actions, seconds
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	75	-	45
-	-	-	-	-	-	105	-	-
-	-	-	-	-	-	-	180	-
-	-	-	-	-	-	30	-	-
-	-	-	-	-	-	55	-	45
-	-	-	-	-	-	67	-	-
-	-	-	-	-	-	170	-	-
-	-	-	30	-	-	-	-	-
-	-	-	-	-	-	37	-	-
-	-	-	-	-	75	90	-	-
-	-	-	-	-	-	-	-	15
-	-	-	-	-	-	97	-	-
Mean						9 times		

TABLE 9. CHRONOGRAPHY OF COIL WINDER'S JOB POSTURE AND MOVEMENTS (TYPE COIL OSP-07)

Coil No.	Time to wind I coil, minutes	Preparatory operations	Basic operations		Adjusting reel, seconds	Conversing, seconds	Other actions, seconds	Walking, seconds	Standing erect, seconds	Standing, stooped, seconds	Changing reels, seconds
			Winding, seconds	Fastening, seconds							
51	4	32	97	60	15	-	-	-	-	-	-
52	4	67	157	45	17+20	-	-	75	-	-	-
53	5	44	97	60	15+5+25	-	-	-	-	-	-
54	5	67	150	82	-	-	-	-	-	-	-
55	5	67	90	135	10	-	-	390	-	-	
56	12	52	120	82	-	-	120	300	-	-	-
57	4	55	107	97	15+10	-	-	-	-	-	-
58	4	105	127	130	12+18	-	-	-	225	-	-
59	12	70	120	74	15+15	-	410	-	-	-	-
60	4	45	130	52	25+5	-	-	-	-	-	-
61	9	52	104	62	-	20	30	90	100	-	60
62	5	74	112	67	20+10+10	-	-	40	-	-	-
63	7	102	195	105	13+17	30	-	44	-	-	-
64	9	52	110	80	15+10	30	-	240	-	-	-
Mean			122	86							

reel. As a matter of fact, reel replacement occurs at different times during winding, and this forces the worker to interrupt the job process frequently. This has a negative effect on winding quality.

Time studies of the executive and preparatory operations were not done at random. In fact, the process of direct winding and fastening was broken down in the executive operations.

Chronography data on the job posture assumed by the coil winder (see Table 9) contain no information on the stress imposed by that posture. No breaks in wire, or rewinding, were observed during the winding process. However, the worker arose from her work site 22 times in 90 minutes in order to straighten out the wire in the "coil." Each time she had to walk around the machine to the left, bend over the "coil," straighten out the wire, return, sit down, and continue work.

Man must stand up during his work because changing the position of the body helps to redistribute muscle stress, and this partially reduces fatigue and retains the ability to work. Yet coil winders stand up primarily in order to replace reels, or in order to straighten out the wire running from the reel to the coil.

The most serious cause of rapid onset of muscular fatigue is static work /69
of muscles. The worker cannot avoid muscle strain because the technology of the winding process requires the constant application of considerable muscular force, most of which is expended irrationally because of poor organization of the job site. The principal sources of excess forces can be considered to be the following:

a stool without a back, causing constant muscular strain;

a high machine, forcing the worker to sit high, but at the same time making the legs provide much of the support force;

presence of a single, flat pedal, placed at the forward surface of the machine, forcing the worker to keep her legs bent at a 90^{o} angle throughout her work shift;

lack of a special foot rest;

constantly unsupported position of the arms.

This constant strained body position has a negative effect on many systems, particularly the vascular system, causing, in particular, a disruption in the blood circulation in the legs.

Time Study of the Job Process

This type of time study is reviewed as an example of an analysis of the dynamics of the capacity of coil winders making the "high" winding of coils to do their job.

Analysis revealed that the work done by coil winders requires great mental strain and emotional stability, expressed by the attention concentration limit (7 to 18 seconds - winding of a layer), the high degree of sensitivity to kinesthetic sensations, absolute coordination, accuracy, and stability of movements made rapidly and constantly for each type of winding rhythm, as well as by constant visual monitoring, and the like. Time spent on the following procedures was isolated for purposes of studying the dynamics of coil winders' capacity to work in terms of production indices:

manufacture of one coil;

overcoming obstacles (breaking of wire, replacement of reel, lack of material, leaving the operator's position);

rewinding.

These criteria were used to compose the scheme for making the time study of the job process (Table 10).

The quantitative results obtained through this scheme provide information /70 on:

the time spent on making one unit of production;

the actual time spent on the winding process during a shift;

total time lost during the work shift;

distribution of time spent on the winding process;

time lost in overcoming each of the obstacles individually;

the dynamics of the capacity to do work;

the possibilities of increasing the productivity of labor by overcoming the obstacles.

TABLE 10. TIME STUDY OF A JOB PROCESS, MINUTES
(TYPE WINDING NOM-6-6000 II, MACHINE NO. 4)

Production sequence no.	Time to manufacture a unit of production (including obstacles	Time to manufacture a unit of production (no obstacles)	Total time spent on overcoming obstacles	Obstacles				Leaving operator's position	Notes
				rewinding wire	break in wire	replacing reel	lack of material		
1	25.58	24.26	1.22	0.5	-	0.72	-	-	-
2	23.15	22.00	1.15	0.7	-	0.45	-	-	-
3	23.10	21.50	1.20	0.6	0.4	-	-	-	Conversed 0.2
4	22.00	20.50	1.10	0.4	-	0.7	-	-	-
5	27.28	22.00	5.28	2.15	1.13	1.4	-	0.6	-

Notes. 1. Column 5 lists minutes required for unwinding, time to overcome the obstacles, and the reason for its occurrence.

2. Column 6 lists the time required to fix a break, and its cause.

3. Column 9 lists the time the worker leaves, and the reason for leaving.

4. Obstacles arising during the work, and not listed in the scheme are entered in Column 10. The time spent on overcoming the obstacles is recorded.

TABLE 11. DISTRIBUTION OF TIME DURING THE PRODUCTION PROCESS

Type part	Total time spent making the part	No. of parts made during time of observation, units	Mean time spent per unit of production, minutes	Interferences, minutes						Total time spent on interferences, min	Total time spent on making parts (without interferences), min	Mean time spent per unit of production (without interferences), min	Anticipated number of coils, units
				Rewinding	Break	Change reel	Leave position	No material	Other				
NOM-6-3000 II	6h45m	24	16.86	28.4	7	23	9	-	1.5	70	5h35m	13.96	29
NOM-6-6000 II	5h40m	15	22.66	29.53	5.17	24.75	6.58	-	-	66	4h34m	19.61	17
NOSK-6-66 II	6h17m	11	34.28	23	5.5	19.58	15.17	-	1.5	55	5h5m	27.72	14

The general characteristic of the distribution of time spent during the process of performing work by one worker, by several workers, or by the whole group of workers, can be obtained by processing and distributing the time study data in accordance with the following scheme (Table 11). /71

The analysis made in accordance with this scheme resulted in a determination of the time spent directly on making the product and on overcoming obstacles interferring with the production process. It developed that the time spent on overcoming all of the obstacles is from 10.1 to 28.2 percent of the total time spent on making the product during the work shift. Moreover, it developed that the most serious obstacles were rewinding (0.2 to 9.1 percent), reel replacement (0.8 to 7.4 percent), and wire breaks (0.3 to 5.5 percent).

A special feature of the types of obstacles indicated is the fact that they not only take time to overcome, but that they also take mental and physical energy. "Confusion" at work takes place quickly when concentration is at a maximum.

Analysis of the reasons why the obstacles arise revealed that the most complicated obstacle is rewinding, which occurs for two basic reasons:

technological (quality of wire, machine adjustment, and others);

psychophysiological (onset of fatigue, evidenced by a breakdown in movement coordination, involuntary loss of attention, breakdowns in psychophysiological stability).

Data were analyzed in accordance with the following scheme (Table 12) in order to establish the main reason for rewinding. /72

TABLE 12. DISTRIBUTION OF TIME LOST REWINDING WIRE AND REASONS

Worker	Type Winding	Total time spent on rewinding		Reasons for rewinding			
		minutes	%	psycho-physiological		technological	
				minutes	%	minutes	%
Z	NOM-6-6000 II	16.24	100	13.74	84.7	2.5	15.3
Sh	NOM-6-6000 II	14.95	100	12.73	85.2	2.22	14.8
Ye	NTMI-10 III	8.33	100	7.96	95.2	0.37	4.8
D	NTMK-10 II	13.33	100	8.0	60.0	5.33	40.0

Analysis of the data established the fact that the main reason for rewinding is early fatigue on the part of the coil winder because the time spent on rewinding attributable to psychophysiological causes was 48.4-100%, and to technological 4.8-51.6%.

The effect of interferences on labor productivity can be analyzed using the scheme that sums the time lost by several workers doing the same kind of work (Table 13).

This analysis establishes the level of productivity of labor in terms of the object investigated and provides a tentative forecast of an increase in that productivity.

TABLE 13. INFLUENCE OF INTERFERENCES ON THE PRODUCTIVITY OF LABOR

Type winding	Total time for winding, hours	Total time for winding (no interference), hours	%	Total time lost, hours	%	Mean time per winding, hours	Mean time per winding (no interference), hours	%	Total no. coils made, units	Predicted number of coils, units	%
NOM-6-6000 II	78.78	66.28	82.2	12.5	15.9	0.4	0.33	82.6	180	238	102
NTMI-10 II	51.38	44.07	85.6	7.31	4.4	0.4	0.37	92.5	132	156.5	118

Graphical method of analyzing time study data

This method clearly illustrates the dynamics of capacity to work for a day, week, month, etc., in terms of production indices. Moreover, it makes it possible to establish the correspondence between the curve obtained for the capacity of the coil winders with already established, typical, characteristics, to do their work, and the curve for the capacity to do work for different job processes. /73

The curves (Figure 7) are constructed from the data listed in columns 1 and 2, as recorded during the time study (see Table 10). The solid line is

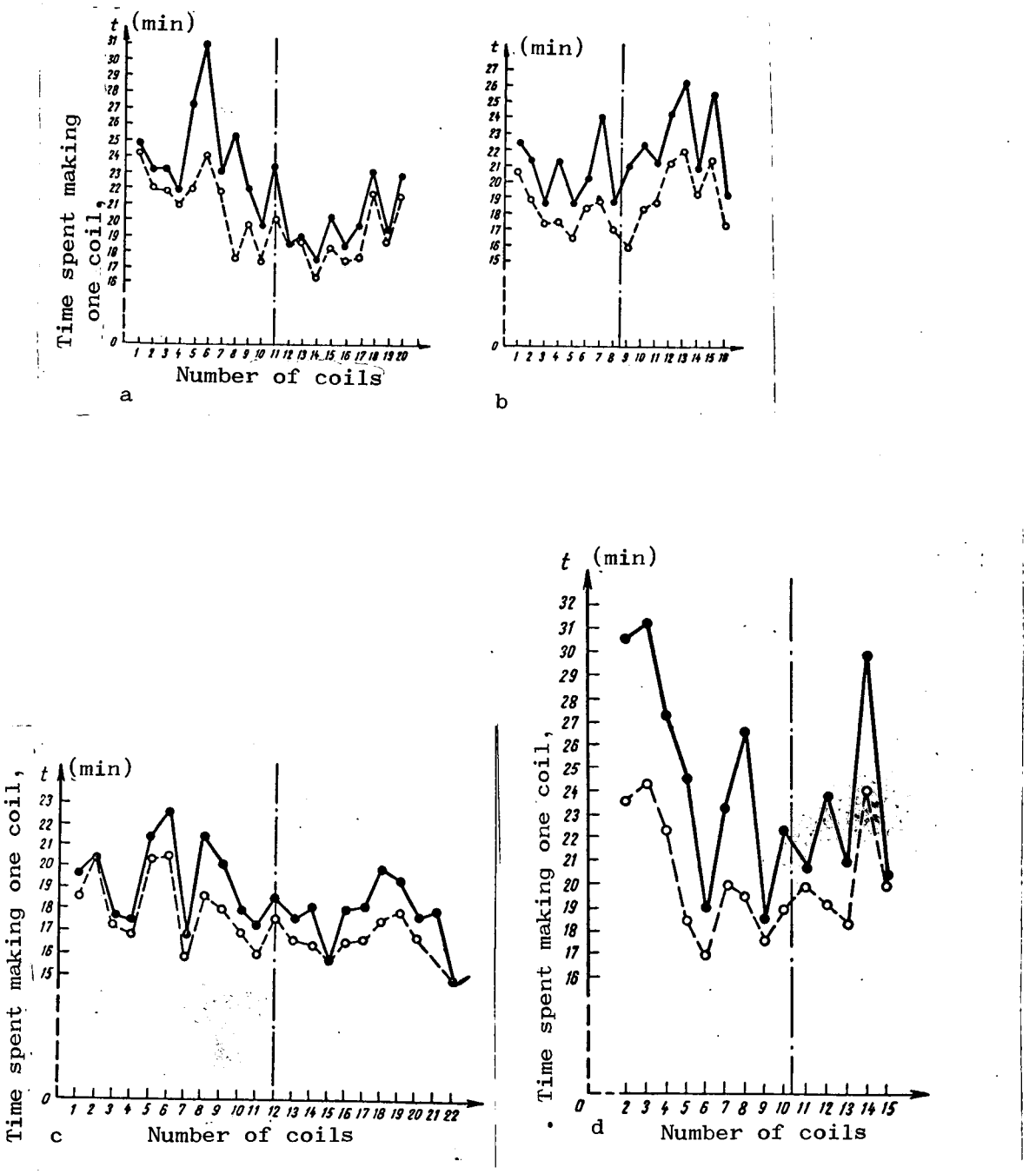


Figure 7. Dynamics of capacity to do work. /74
a - machine No. 4, type winding NOM-6-6000 II; b - machine No. 4, type winding NTMI-10 II; c - machine No. 4, type winding NTMK-10; d - machine No. 5, type winding VOS-1 II, III.

actual time spent winding the coils. The dashed line is for the same factor, but when there was no interference. The vertical line is the dinner break.

Analysis of these graphics revealed that there was no behavior pattern in /75 the change in the capacity to do work among the female coil winders observed that would make any significant reduction in the efficiency of their work.

***

The result of the work done was the development of a complex procedure for making an ergonomic analysis of the performance of machine workers that can be used in a variety of different plants.

Complex investigation of the organization of performance by workers by using this procedure has made it possible to uncover a number of serious shortcomings that greatly reduce the effectiveness of their work.

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CHAPTER 3

SELECTION, EDUCATION, AND TRAINING OF OPERATORS FOR THE "MAN-MACHINE" SYSTEM /77

Rational selection of operators based on a determination of the correspondence between their personal qualities and vocational requirements is one way to provide for highly efficient functioning of control systems, including the human one.

The fitness of a man for a concrete job is determined by vocational orientation and vocation selection methods. Vocational orientation is a system for evaluating a man's personal attributes, his interests and aptitudes, and for establishing those vocations best suited to his capabilities.

The vocation selection system finds those candidates in a particular specialty who, in their individual attributes, most nearly correspond to the requirements of that specialty; that is, those fitted for education and subsequent work in the particular specialty.

Thus, the task of determining vocational suitability has two aspects. One is the selection of the most suitable types of vocations for a concrete person. The other is to select from among a group of candidates for a particular specialty those persons from whom one can expect successful accomplishment of the particular job.

Vocational orientation, because it is part of the overall state problem of rational distribution of human resources among the various vocations, has not yet received the methodological justification it needs. At the same time, cer- /78
tain types of vocation selection (in terms of medical indications, physical condition, educational qualifications, etc.) are widely used, particularly where specialists with an operator's profile are involved.

Psychophysiological selection is a component part of vocation selection. This saves a great deal of time and money in training operators, as well as in screening persons undergoing training.

Foreign experience reveals that the use of vocation selection in the acceptance of students for flight school has greatly reduced subsequent screening for lack of success as a pilot from 75 to 36 percent in the U. S. Air Force,

from 50 to 30 percent in naval aviation in the U. S. Navy, and from 61 to 36 percent in the French Air Force. Also established was the fact that vocation selection saves a great deal of money, some $1 million for every 100 pilots completing their training successfully, while at the same time providing the forces with better qualified specialists in a short period of time [1]. The data shown in Figure 1 indicate that those chosen during the selection process usually complete their training with higher grades, and then perform more effectively.

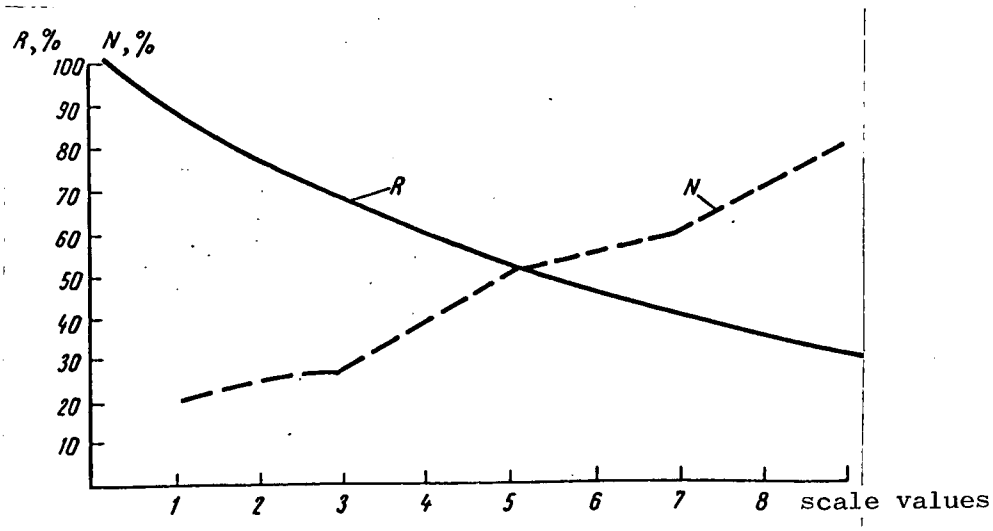

Figure 1. Number of students completing training successfully N, and the cost of their training R, in terms of the grade received on examintation.

1. Fundamental Principles of Vocation Selection /79

Development of a specialist selection system should be based on principles determining the content and the sequence in which the selection measures are realized.

The complexity of vocation selection, which includes evaluating the suitability of candidates on the basis of a set of indices, physiological, mental, physical, social, and others, is the first principle. In other words, vocation selection should be complex and systematic in nature, envisaging an overall study of the person.

One of the difficulties encountered in vocation selection is the establishment of objective suitability criteria. These criteria cannot be fixed rigidly because they change with conditions, particularly with control system

parameters, type of activity, permissible time, characteristics of the education and training process and, finally, the social and economic potentialities of selection. Hence the need to determine the various degrees of suitability of the candidates.

Activeness of selection is the second principle. The ever-increasing complexity of technical systems has brought with it sharply increased requirements, imposed on those servicing these systems. The selection system therefore should take into consideration various ways to increase job efficiency, particularly realization of necessary ergonomic and engineering-psychological recommendations.

The third principle is differentiability of prediction. This means that the most desirable approach is to develop procedural selection methods and criteria for groups of specialties combining the community of activity and the vocationally significant attributes of the person. This principle does not preclude the possibility, and in a number of cases the need, to develop methods and criteria for selecting candidates for individual specialties.

The fourth principle, the dynamism of selection, involves the continuous accumulation of information on the condition and characteristics of the development of the person's vocational ability and potentialities. This information is needed to refine the prediction of how successful the training of specialists will be, and to answer the question of how they should be distributed.

Development of the selection system envisages providing answers to the following questions.

1. Determination of concrete specialties, or groups of specialties, for /80
which a selection system must be developed (clarification of the desirability of creating a selection system for candidates for a concrete specialty).

2. Determination of the tasks of psychophysiological selection; prediction of suitability for training, for practical work under real conditions, under extremal conditions, etc.

3. Study of the physiological-hygienic and psychophysiological characteristics of job performance; analysis of the job process to determine requirements candidates must have.

4. Development of procedural methods for evaluating personal, vocationally important attributes (depending on the tasks imposed on selection, on the stage at which selection is made, and on the nature of the job).

5. Evaluation of the predictability (informativeness), of the dependability, and of the differentiability of procedural methods of psychophysiological examination, for determining the criterion of vocational effectiveness of specialists.

6. Development of criteria for use in evaluating the person's vocationally important attributes.

7. Verification of criteria already developed for predicting the vocational suitability of operators, of the degree to which the psychophysiological predictions based on factual data and the vocational efficiency the operators correspond.

8. Development of organizational and procedural forms for making the psychophysiological selection.

2. Original Propositions for the Development of a Vocation Selection System

A vocation selection system can be developed for concrete specialties, as well as for a group of specialties, united by the commonality of the psychophysiological qualities demanded of personnel.

The need to develop a selection system arises when:

the success in training specialists depends to a significant degree on the status of vocationally significant psychophysiological functions. The inadequate development of these functions among a particular group of trainees is the cause of their poor training;

there is a sharp difference between good and poor specialists in /81 terms of the efficiency with which they do their jobs (based on the number and nature of the mistakes permitted them while they are doing their jobs, etc., for example), the result of the difference in the degree to which definite psychophysiological functions are developed.

Once the concrete specialties, or groups of specialties, for which a selection system must be developed have been established, it becomes necessary

to formulate the selection task: for subsequent training; for practical work, and the like. Consideration also must be given to the fact that because of the differences in the nature and conditions of vocational activity on the part of operators, endowing that activity with a high degree of efficiency will depend on personal attributes, or on the degree to which individual attributes are developed.

An important link in the development of a psychophysiological selection system is the determination of the requirements to be imposed on candidates for training in a particular specialty; that is, revelation of personal psychophysiological functions, emotional and volitional, and other characteristics ensuring successful mastering and accomplishment of the individual job operations, and of the whole job process.

We must, in order to study the characteristics of the job process, and the conditions under which the operators work, for purposes of subsequent determination of vocation requirements, use the set of procedural methods for composing the psychophysiological characteristics of the object, weapon, conditions, and organization of the work.[3]

A primary job description is written in order to develop vocation requirements. This requires:

a determination of those basic tasks (stages, cycles) of the job subject to further, detailed analysis (these usually are the most complicated and critical tasks);

isolation of the key operations, the actions on the part of the operator establishing the specifics of the job process under study;

study of the organizational structure of operator performance, and of the nature of his connection with other operators;

a determination of the flow of information to and from the operator;

an evaluation of the load on the information transmission channels, /82
as well as a determination of the most heavily loaded functional systems of the organism ensuring receipt, or transmission, of information;

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[3] These methods are described in Chapter 1.

a determination of job time parameters (duration of individual job operations, length of pauses between operations, etc.).

These data are used to refine the primary job description, as well as to provide supplemental information for use in fashioning the secondary job description. The results of the engineering-psychological examination of control panels and operators' positions, of the study of the environmental factor indices, of the recording of individual job parameters, of the investigation of the status of certain psychophysiological functions, etc., should be the basis for this latter job description.

The secondary job description should reflect:

the nature of the logical structure of the actions by a specialist in performing a concrete task (sequence of actions, their interrelationship, etc.);

the characteristics of perceptive and motor actions while the work is being done (their physical and mental sense);

the presence of unfavorable environmental factors that are the cause of nonspecific stress on operators and of reduction in the stability of psychophysiological functions, or of direct interference in carrying out specific job operations; the nature of these factors (their physical nature);

the nature of spoken information; types (directive, informative, etc.), volume, sequence of arrival, and transmission;

frequency and sequence of conversion into elements of the sensory and motor fields for control panels, degree of complexity of these operations;

status of mental and physiological functions of specialists as they perform definite tasks, degree of stability of these functions in the face of the effects of environmental and job process factors.

Development of vocation requirements is completed with justification of the degree of significance of individual personal qualities developed during the psychophysiological analysis for a specific type of activity, and by a determination of the most important of the qualities that should be evaluated /83 when operators are selected.

The essence of the procedure for making a quantitative evaluation of the degree of significance of the psychophysiological qualities is that once the verbal algorithm for the process has been composed, the personal properties

which ensure realization of each of its elements (operations) can be determined. The psychophysiological functions discovered during this analysis can be evaluated on a 0-6 scale in accordance with the characteristics presented in Chapter 1.

Once the summary evaluation is made, the significance of each of the psychophysiological functions, and their range, can be developed, or selected from among existing methods for studying personal vocation aptitudes (vocationally important qualities).

3. Procedures for Studying Personal Vocation Aptitudes

Vocation aptitudes are the set of quite stable personal qualities which, while they can change as a result of indoctrination, education, and training, determine how successful future performance will be.

The job performance of an operator will be determined by "personal operational aptitudes", ensuring that the information conversion process (perception, memory, muscular, and others) in particular will be carried out, and by "personal activation characteristics"; that is, by properties that assign and direct a definite level of functioning of the human information conversion processes (personal direction, attention, characteristics of the volitional sphere, and the like). Activation characteristics, like character traits, are a definite set of personal attributes, and should be taken into consideration in the selection process.

Determination of methods to use to investigate vocation aptitudes, and selection of methods to use to study the status of psychophysiological functions, is extremely complicated. The greatest difficulty perhaps stems from the fact that no one aptitude can be expressed by a single measurement. Different levels of realization of aptitudes too require different methods to describe them, and different units by which to measure them.

Two basic experimental methods for use in studying vocation aptitudes are analytical, and synthetic.

The analytical method includes ways to investigate individual psychophysiological functions, processes, and personal attributes. In turn, these can be broken down into direct methods for studying the psychophysiological qual- /84

ities under ordinary conditions (in "pure" form), and situational methods for investigating the characteristics of the manifestation and realization of these qualities under complex conditions (the effect of extremal factors, stress situation, and the like). Direct methods can be elementary, directed at evaluating individual psychophysiological functions (determination of absolute and differertial thresholds of sensitivity of analyzers, times of simple sensory and motor reactions, and others), and complex (perception of space, speed, for example).

Situational methods include relevant methods, in which the factors complicating the realization of some particular psychophysiological quality are an integral part of the task (so far as their physiological and semantic parameters are concerned), and irrelevant methods, in which factors of this type are external effects of an activation (creation of a definite situation for the experiment, motivation of subject, and the like), or load (time limits, outside interferences) nature, on the subjects.

Included in the synthetic investigation method are those of the form and instrument type based on simulation, or modeling, of individual job operations, of their totality, or of the operation as a whole. This method includes:

functional methods, determined by the characteristics of the set of vocationally significant psychophysiological functions for some activity (or types of activity) reproduced by them; their form is abstracted from a concrete job process (work operation);

elementary-operational methods based on the reproduction of individual operations, the effects of a concrete action;

structural-operational methods, reproducing the entire action, or a definite set of job operations characteristic of a concrete job process.

Functional methods include those using forms reproducing a set of functions mainly of a perceptive-logical nature, as well as instrument methods designed to reproduce the combination of functions, primarily of a perceptive-motor nature. Elementary-operational and structural-operational methods are simulative in na- /85
ture, and reproduce concrete operations, job operations, or the operation as a whole.

All of these procedural methods can be used to obtain static personal characteristics determining the status, the level of development, of specific psychophysiological functions, vocational skills, etc., or dynamic personal characteristics revealing the characteristics of the development, of the improvement, in these functions, and, in the final analysis, the trainability of the subjects, and the tendency to develop vocational aptitudes, depending on the purposes of the investigation.

The final decision on the selection of one of the two methods noted has not yet been made.

There are a number of theoretical considerations that force one to give preference to the first method. Any job process can be considered a sequence of definite actions, the quality of completion of which will depend on a number of human psychophysiological characteristics, each with different significance and weight for each action, as well as for the same action performed under different circumstances. The suitability of a man for a concrete specialty, and this is true for all specialties, requiring the same combination of these characteristics, can be established by determining the level of these characteristics, and combinations of them.

The synthetic method is desirable for distributing school graduates and for solving the problem of assigning specialists to definite technical objects when the personnel examined already have job experience. If the structure of the system (of the object) is partially, or completely, different from the structure used to select the technical means, the use of this method to predict the aptitude of a man for a concrete performance is scarcely desirable (having in mind a situation in which a specialist, without changing his job description, is forced to switch to activity differing from the preceding one). It should be noted that the use of the synthetic method generally is impossible without preliminary training of candidates when selecting for certain specialties, particularly those with an operator's job description.

Methods adequate for the properties studied should be used to obtain objective or complete information on the status of particular personal attributes, or of all of them. /86 And it should be remembered that different manifestations of a particular attribute, as well as different types of interrelations between

the particular attribute and others (such as memory in connection with the characteristics of perception, attention, emotional stability) can be investigated, depending on the nature of the task (content and form of the presentation). The investigator, in studying personal attributes therefore should have at his disposal an adequate variety of procedural methods (Table 1).

There are a number of requirements imposed on procedural methods recommended for vocation selection, including the degree of correspondence between the methods (or individual indices of the methods). These requirements should be verified experimentally. The following are the main ones.

TABLE 1. LIST OF PROCEDURES FOR STUDYING THE JOB PERFORMANCE OF OPERATORS /87

Psychophysiological functions and their elements	Procedures, methods, and parameters measured	Literature
1	2	3
Perception of intensity of stimulus	Absolute threshold of light sensitivity (adaptometry)	7, 10
	Threshold of contrast sensitivity	10
	Absolute threshold of audio sensitivity (audiometry)	10, 13
	Differential threshold of audio sensitivity	10, 13
	Absolute threshold of vestibular sensitivity	10, 13
	Test for nystagmis	10
	Absolute and differential thresholds of tactile sensitivity (Frey hairs method)	10
	Differential threshold of kinesthetic sensitivity (mercury dynamometry)	10, 14
Perception of frequency of stimulus	Pigment tables method	10
	Anomaloscopy	10, 13
	Differential audio threshold in terms of frequency	7, 10, 13
	Determination of rhythmic sensitivity of hearing	10

Psychophysiological functions and their elements	Procedures, methods, and parameters measured	Literature
1	2	3
Perception of spatial extent of stimulus	Determination of keenness of vision	10, 13
	Determination of field of view	10, 13
	Investigation of stereoscopic vision	10, 13
	Investigation of binocular recording reflexes	10
	Investigation of accomodation reflexes (determination of close and closest points of clear vision and scope of accomodation)	10, 14
	Visual ergography method	10 /88
	Determination of minimum speed of shifting object	10
	Method for determining sound source	10
	Determination of differential thresholds in terms of distance to tactile analyzer	10
	Reproduction of specified movement	10
	Determination of position of body in space	10
Perception of time stimulus acts	Critical frequency of merging of light flashes	10, 14
	Stability of clear vision	10, 14
	Critical frequency of merging of sound bursts	10
	Time differential of audio sensitivity thresholds	10
	Determination of recognition threshold	10
	Determination of "time sense"	14
Short memory	Volume of direct memory ("memorizing numbers")	17, 26
visual graphic	"Number memory" (memorizing 12 numbers)	14

Psychophysiological functions and their elements	Procedures, methods, and parameters measured	Literature
1	2	3
	"Memorizing 10 words" ("memorizing work")	12, 13
	Tables of instruments	
	"Memorizing geometric figures" ("visual memory")	18
	"Memorizing subject pictures"	18
oral-logical	"Reproduction of text" ("memorizing a short text")	12, 13
	"Memorizing 24 numbers"	
	"Word association"	
Long memory	Method of synonyms	18
	"Reproduction of words by indicated letter"	18
Operational memory	"Reading of numerical series"	10 /89
	"Establishment of behavior patterns"	10, 11
Reproductive thought	Procedures based on an understanding of simple laws	
	Meade test with transmissions	26
	Elementary arithmetical operations procedures	
	"Scales"	
Productive thought	"Syllogisms"	
	"Establishment of the behavior pattern for a numerical series"	26
	"Assembly of a cube"	12, 13
	"Fourth extraneous"	9, 18, 26
	"Exclusion of third"	9, 18, 26

Psychophysiological functions and their elements	Procedures, methods, and parameters measured	Literature
1	2	3
	"Free classification"	9, 18, 26
	"Reinstatement of opinions from a specified set of words and determination of their intensity"	26
	"Filling in of gaps in opinions"	18
	Methods of nonstandarization of thought	15
	"Thoughtful sectioning of figures"	1
	"Compasses"	
Psychomotor	Procedures for the investigation of sensomotor reactions	12, 13, 14, 16
	"Tipping test"	14
	Reaction to a moving object	14
	Dynamometry	14
	"DKN-3" procedure	
	"Emotional coordinometer"	16
Attention	"Retrieval of numbers"	12, 13, 19
	"Arrangement of numbers"	
	Tachistoscopy	
	"Number-letter combinations"	
	Attentiometry	16
	Complication apparatus	19
	Proof test	12, 14
	"Continuous counting at a specified tempo"	13
	"Counting off" procedure	19

Psychophysiological functions and their elements	Procedures, methods, and parameters measured	Literature
1	2	3
	Retrieval of numbers with switching	12, 13, 19
	"Two scales" method	
	"Addition of numbers with switching"	12, 13
	"Numerical series"	7
	"Rybakov method"	18

Note. Study of the "activation attributes of the person" and her characterological features usually is made by the meeting and observation method because the experimental methods developed for these purposes are quite complicated. Their use is extremely limited.

Predictability (informational) value of the techniques. This index discloses the difference in psychophysiological functions among persons with different levels of development, with different degrees of training. In other words, the predictability value of the techniques is determined by the possibility of a correct forecast of the vocational effectiveness of the persons examined. The predictability of the technique can be measured by the coefficient of correlation between the results of the examination and external objective criteria for insight into the condition for which they are used.

Determination of the predictability value of the technique (of individual indices, criteria, of the technique) reduces, in principle, to the establishment of the degree of significance in the difference in the distribution of the particular criterion, usually obtained from examinations made of two groups of persons on the basis of special or generalized criteria of job efficiency, or other predicted indices. Pearson's criterion is recommended for solving this problem (the chi-square criterion) [3, 22, 24].

The following rules must be observed in order to discriminate in terms of criterion gradations:

an attempt must be made to isolate that subrange of the criterion (the gradation) in which the frequency of the appearance of the subjects from both groups differs maximally;

too sharp differences between the probability relationships in adjacent gradations must be avoided;

at least 5 to 7 persons from each group should be in each gradation.

Technique reliability. This is the measure of the stability of the results, obtained with the help of a specific technique in the course of repeated investigations of the same subject. A high degree of reliability of the technique will permit using its results for the general evaluation. The reliability can be measured by the coefficient of correlation between the individual series of results obtained by examining a group of subjects by the same technique.

The following indices can be used as a measure of reliability: dispersion in measurement errors; coefficient of reliability; coefficient of paired rank correlation.

Differentiability of techniques. This requirement means that each technique should be directed at evaluating a definite functions. The correlation between the results of the technique selected and the other techniques directed /91 at evaluating what are known to be other functions, must be slight as possible. The correlation matrix (of materials from a pairwise comparison of the results of different techniques) should be calculated in order to determine the differentiability of the technique.

The following principles should govern in developing techniques providing for an adequate level of forecasting value and reliability.

The principle of soundness. The techniques should ensure investigation and evaluation of personal qualities developed from psychophysiological analysis that are important for a particular type of activity. The quality being studied, and why it, in particular, should be evaluated, should be clear.

The principle of objectivity anticipates the need to create and maintain throughout the period of examination the standard quality of the situation, the examination techniques, instruction, organizational forms of the experiment, the recording and analyzing patterns, and the methods used to interpret the results of the investigation. Insufficient standardization of conditions under which the investigations are made results in a reduction in the reliability of the techniques, and, as a result, in their value.

The principle of practicality. The techniques should be such that their use did not require lengthy preliminary training of the subjects. It is desirable that they be economical in terms of cost for equipment, in the conduct of the investigation, and in processing results, as well as in terms of the time spent making the investigation. The techniques should be simple, and, in so far as possible, provide for mass examination with the participation of a limited number of supervisory personnel.

Verification of the scientific value of methods for use in making an experimental study of capabilities depends in large measure on the criteria used for their preliminary evaluation. As already has been pointed out, a comparison must be made between the results of the psychophysiological examination of specialists and the level of their practical training, or professional qualification, in order to determine the forecasting value of the techniques (or of their indices).

The judgment made of the level of training, or qualification, should be based on an analysis of the quantitative values of the indices of vocational efficiency of specialists.

The general requirements for indices of vocational efficiency can be reduced to the following: adequacy of the indices in terms of the aims of the selection and the peculiarities of the vocational activity; advantageous use of indices providing an objective characterization of productivity of activity (in the broad sense of this word); presence of a generalizing, or basic, index when the evaluation of the vocational efficiency is made using two and more indices. /92

The specific tasks of the selection must be taken as the origin when selecting the indices and evaluating their adequacy. If, for example, the basic, or immediate task of training radiotelegraphers is the teaching of the reception and transmission of information with a specific piece of communication equipment, it is obvious that the basic indices selected should be those characterizing the teaching of these skills within a definite time frame. At the same time, the specific indices of trainability can be the quantitative and qualitative characteristics of the job, such as speed of reception and transmission of information; the relative number of permissible errors while so doing, etc.

4. Principles and Rules for the Classification of Personnel Undergoing Vocational Selection

There are a variety of approaches that can be taken to the principles of classifying personnel undergoing selection. One approach is to use the sample discrimination theory to construct an algorithm. It has advantages over other known approaches in that it can be used to establish a scientific basis for a scaled system for evaluating the quality with which the different tests are completed, and to set limits to the scale used to establish with specified probability the suitability (or unsuitability) of candidates for work in a particular specialty.

The development of the original data for the algorithm begins with the compilation of the diagnostic information. The first thing that must be determined is the results that can show which of the individuals taking the tests are clearly suited for the particular work (Group A) and clearly unsuited (Group B).[4]

This can be done by getting a group of people whose capabilities for working in the particular vocation are unknown, to do tasks designed to evaluate the individual characteristics of candidates in accordance with requirements developed from the results of a job description analysis of this specialty. /93 The results of how these tasks are performed by each of those participating in the experiment are recorded in the form of a set of values of test indices, after which all personnel, regardless of the results of how they performed the tasks, are given the full course of training for work in the particular vocation.

The work of each is evaluated at different stages, and at the end of the training. A judgment as to the desirability (or undesirability) of the use of each in the particular job then is made.

After this experiment the researchers have at their disposal the values of the test indices q_1, q_2,..., q_n, characteristic of the individuals of groups A and B.

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[4] Groups A and B sometimes are called polar groups.

Starting with the theory of the verification of statistical hypotheses, it can be considered that an individual with a definite set of test index values, q_1, q_2,..., q_n, falls in group A, or B, depending on whether or not the logarithm of the probability ratio

$$L(q_1, q_2, \ldots, q_n) = \ln \frac{f_A(q_1, q_2, \ldots q_n)}{f_B(q_1, q_2, \ldots, q_n)} \tag{1}$$

exceeds some constant L_0 providing a permissive level of errors of the first α and second β kind (here α is the permissible probability of selection of an unfit candidate; β is the permissible probability of missing a good candidate).

The functions f_A and f_B in Eq. (1) are the conditional density distributions of the set of test indices, q_1, q_2,..., q_n, in each of the groups. This expression can be simplified somewhat if the test indices are considered to be independent. Then

$$L(q_1, q_2, \ldots, q_n) = \sum_{i=1}^{n} L_i(q_i) = \sum_{i=1}^{n} \ln \frac{f_A^i(q_i)}{f_B^i(q_i)}, \tag{2}$$

where $f_A^i(q_i)$ и $f_B^i(q_1)$ are the density distributions of the i^{th} index of tests in each of the groups.

The logarithm of the ratio $\frac{f_A^i(q_i)}{f_B^i(q_i)}$ can be called the diagnostic coefficient, or the scale value of the i^{th} test index.

Thus, the rule for the classification of individuals undergoing vocational selection (the conditions for equating them to the fit or unfit category) can be formulated as follows: /94

the candidate is considered to be fit for work in the particular specialty if the index is

$$L \geq L_0, \tag{3}$$

and unfit if

$$L < L_0, \tag{4}$$

where L is the algebraic sum of the scale values attained by the candidate as a result of work with the tests during the first stage of selection; see Eq. (2);

L_0 is the boundary value of L for the particular specialty.

The value of L_0 can be obtained as follows. The known values of the test indices, q_1, q_2,..., q_n are used to find the values of L_{A_i} and L_{B_i} values obtained in each of the groups statistically, the empirical functions for the distribution of the values of the summed index in each group are constructed.

The distribution functions $F_A(L)$ and $F_B(L)$ thus obtained are the original functions for establishing the boundary value, L_0, based on the condition that provision is made for an acceptable level of values for errors of the first and second kind.

If the conditions of the future activity impose no complicated (increased) requirements on the candidate, polar groups, for all practical purposes, cannot exist. Then $\alpha \approx 1 - \beta$, and there is no selection problem. But if these requirements are sufficiently complex, and if, in practice, there is a quite obvious separation into polar groups, the α and β interdependency will be reduced to a minimum.

In the general case, the α and β interdependency depends on the level of requirements imposed on the selectee.

The permissible value of the most critical type of error must be the first thing selected in each specific case when selecting the quantitative values of α and β.

If, for example, it is necessary to select a small number of persons from /95
a large group of candidates, and if the selection of an unfit candidate can result in a significant reduction in system operating efficiency, at the same time that missing a good candidate would not cause any great loss, the most critical is the error of the first kind, and an α value should be selected that would, in this case, be quite small. Graphical means can be used to find β and L_0. If the β and L_0 values obtained do not meet the requirements as established, the value of α previously used must be refined.

When a large group of people is being examined, two thresholds, L_0' and L_0'', can be established. The former corresponds to the minimum probability of selecting an unfit candidate, the other the minimum probability of missing a good candidate. Taking α_{min} and β_{min} as close to zero, all candidates undergoing selection can be broken down into three groups:

personnel for whom $L \geq L'_0$ equates to the category of those fit for work in the particular specialty;

personnel for whom $L \leq L''_0$ equates to the category of those unfit to work in the particular specialty;

personnel for whom $L''_0 < L < L'_0$ can be considered as a reserve to add to the group of fit candidates.[5]

Let us consider the sequence in which the calculation of the original data for practical use of the principles and classification methods set forth above is made.

The statistical distribution functions in $F_A^*(q_i)$ and $F_B^*(q_i)$ are constructed from the results of tests taken by personnel clearly fitted and clearly unfitted for work in the particular specialty. These then are smoothed and differentiated (by a graphical method, for example). The distribution densities obtained for the i^{th} test index in each of the classes $f_A^i(q_i)$ and $f_B^i(q_i)$, are the originals for claculating the scale values

$$L_i = l_n \frac{f_A^i(q_i)}{f_B^i(q_i)} \qquad (5)$$

The scale values, L_i, calculated can be represented graphically in the form of a continuous function.[6] The values of the function can be tabulated with a quantization step, thereby deriving tables of scale values (of diagnostic coefficients) for the different tests. Figures 2 through 5 are included to illustrate the statistical $F_A^*(q_i)$ and $F_B^*(q_i)$, smoothed $F_A(q_i)$ and $F_B(q_i)$ distribution functions, distribution densities $f_A(q_i)$ and $f_B(q_i)$, and the curves for the scale values L_i for the "Points on a Screen" and "Arrangement of Numbers" tests. The scale values for evaluating the success with which the tasks in the two tests are accomplished are listed in Table 2. /96

Analysis of the distribution functions $F_A^*(q_i)$ and $F_B^*(q_i)$ leads to the following conclusions.

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[5] The gradations listed are correct within the same probability as that taken for the α and β values.

[6] This function can be used to evaluate the informativeness of the test indices as well.

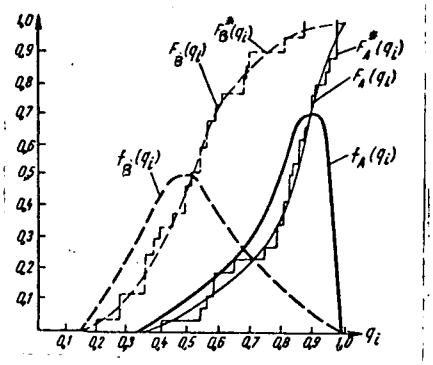

Figure 2. Statistical and smoothed distribution functions $F_A^*(q_i)$, $F_B^*(q_i)$ and $F_A(q_i)$, $F_B(q_i)$, probability density functions $f_A(q_i)$, $f_B(q_i)$, of the index q_i for the "Points on a Screen" test in groups A and B.

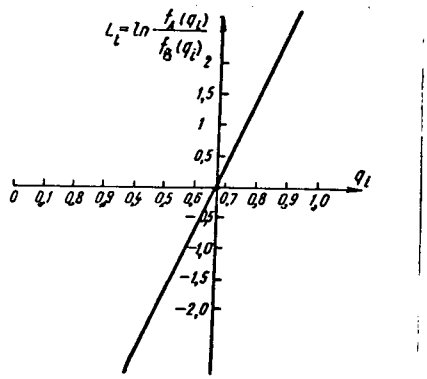

Figure 3. Curve of the function $L_i=f(q_i)$ for the "Points on a Screen" test.

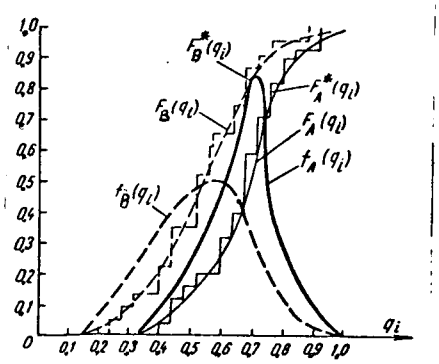

Figure 4. Statistical and smoothed distribution functions $F_A^*(q_i)$, $F_B^*(q_i)$ and $F_A(q_i)$, $F_B(q_i)$ probability density functions of the index q_i for the "Arrangement of Numbers" test in groups A and B.

The distribution of test indices usually differ from a normal distribution. The distribution most often found is skewed (asymmetrical). That found somewhat less frequently is very nearly uniform, and there is an occasional, sharply peaked, distribution. One of the main causes of the deviation from the normal of the distributions obtained in practice is the qualitative nonuniformity among the persons undergoing examination. However, the causes of the deviation in the type of distribution from the normal are not as important as investigation of the causes of change in the type of distribution when going from one test to the other, and particularly the reasons for the difference in distributions for groups A and B taking the same test. Since the type of distribution is what, for the most part, predetermines the quantitative characteristics of the selection parameters, the polar group formation process requires an unusually precise approach.

A detailed examination of the function $L(q_i)$ will reveal certain behavior patterns, despite the nature of its change for different tests. This function has sharply expressed sections that increase linearly, it has plateaus, etc., for certain tests within definite ranges of values for test index q_i. This nature of the change in this particular function ought not be considered a random one because it repeats when similar tests are used for other specialties. These behavior patterns can be explained by the capabilities of /97 the man taking specific tests, and by the "designed" features of these latter.

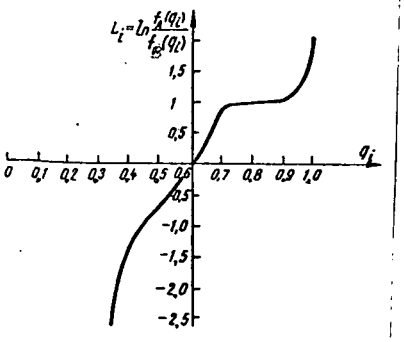

Figure 5. Curve of the function $L_i=f(q)$ for the "Arrangement of Numbers" test.

Some inaccuracy is possible when constructing the distribution functions $F_A(q_i)$ and $F_B(q_i)$ from limited statistical data, particularly over the terminal sections. It is over these latter /98 that the function $L_i=\ln \frac{f_A(q_i)}{f_B(q_i)}$ usually tends to $\pm \infty$, so rational limits for its practical use should be introduced. Establishment of these limits will eliminate cases of unjustified excessive (insufficient) weight being given to some tests over all the others.

There are other methods that can be used to solve the problem of classifying personnel undergoing selection. One reference, [5], recommends an algorithm based on the ideas of successive statistical analysis [4]. /99

TABLE 2. L_i SCALE VALUES FOR THE TWO TESTS

"Points on a Screen" Test		"Arrangement of Numbers" Test	
Value of index	Scale Value	Value of index	Scale Value
< 0.35	-3.6	< 0.35	-2.6
0.35	-3.4	0.35	-2.4
0.36	-3.2	0.36	-2.2
0.37	-3.0		
0.385	-2.8	0.365	-2.0
0.405	-2.6	0.375	-1.8
0.425	-2.4		
0.445	-2.2	0.39	-1.6
0.467	-2.0	0.405	-1.4
0.49	-1.8		
0.51	-1.6	0.42	-1.2
0.53	-1.4	0.445	-1.0
0.55	-1.2		
0.57	-1.0	0.485	-0.8
0.59	-0.8	0.519	-0.6
0.61	-0.6		
0.63	-0.4	0.55	-0.4
0.65	-0.2	0.58	-0.2
0.67	0		
0.69	0.2	0.61	0
0.71	0.4	0.63	0.2
0.727	0.6		
0.75	0.8	0.66	0.4
0.77	1.0	0.675	0.6
0.785	1.2		

"Points on a Screen" Test		"Arrangement of Numbers" Test	
Value of index	Scale Value	Value of index	Scale Value
0.805	1.4	0.69	0.8
0.825	1.6	0.73 + 0.92	1.0
0.845	1.8		
0.865	2.0	0.95	1.2
0.885	2.2	0.97	1.4
0.905	2.4		
0.925	2.6	0.985	1.6
0.945	2.8	≥ 0.995	1.8
0.962	3.0		
0.97	3.2		

The first thing that must be done in order to use this algorithm is to obtain the scale values (the diagnostic coefficients) $L_i(q_i)(i = 1,2,\ldots,n)$ for all n for the selected criteria for the individuals tested. The method used to obtain the function $L_i(q_i)$ was similar to that described above.

Known methods are used to order the selected criteria in terms of informativeness. Correlation matrices are constructed because when there are two dependent criteria, one is highly informative, so the use of successive statistical analysis requires the availability of independent criteria.

The successive statistical procedure to determine the particular class to which the individual being evaluated belongs is as follows.

The sum (K) of the first scale values (diagnostic coefficients), arranged in descending order of informativeness of selected criteria, is calculated in sequence.

If

$$\sum_{i=1}^{K} l_i(x_i) > \ln \frac{1-\beta}{\alpha},$$

the individual being evaluated belongs to class A, and if

$$\sum_{i=1}^{K} l_i(x_i) < \ln \frac{\beta}{1-\alpha},$$

he belongs to class B, and the procedure is completed at the k^{th} step. If all selected criteria are used and the procedure is not concluded, there is not

enough information. The values of the errors of the first and second kind are selected with consideration given to the real situation that arises when solving a specific problem, and as distinguished from the preceding algorithm, in this algorithm α and β are independent.

It should be noted that the use of a particular algorithm requires detailed calculation of the peculiarities of the specific selection problem being solved, and careful study of the original premises used as the basis for concluding that the proposed statistical methods were usable. /100

One type of vocation selection is that of specialists on the basis of indices for quality of work done right on the job. This is done by using what are primarily synthetic methods of examination with the aid of simulators, technical equipment for training, special modeling devices, mockups of job sites, and others.

The special aspect of this type of selection is that the forecast of the possibility that the candidate will be able to master the specialty is made as a result of his working in real situations rather than by an indirect method (tests). This manner of making the selection definitely coincides with the initial stage of the training given the operator in doing his functional duties.

It is at this stage that the original level of training of the candidate to work in the proposed specialty, W_0, his capacity to be trained, t_0, time required, t_R, possible expenditures on training, R, and expected effectiveness of his work, Q, can be evaluated. Probability, time, or accuracy with which he does some particular operation (or set of operations), can be used as indices of effectiveness of the work done by the operator.

That index evaluating the operations completed by the candidate significantly effecting the final results of the work is selected in each specific case. The effectiveness of the work done by a candidate can be evaluated with the help of the following expression (see Chapter 8)

$$Q_{\xi i} = Q_{max\,\xi i}\left(1 - W_{0\xi i}\, e^{-\frac{t}{t_{0\xi i}}}\right). \qquad (6)$$

All candidates selected as a result of taking tests are given on-the-job training under conditions most characteristic of their future activity (ξ_i) .

Some definite time later (1 to 2 hours, for example) a control record is made of the values of the selected index of effectiveness of the work done by the operator. The data obtained are approximated by the exponential function (by the model of trainability) given above.

The values of $t_{O_{\xi i}}$ and $W_{O_{\xi i}}$ are found graphically, or analytically, for each candidate and then are used to calculate the probable time that will be required for his training (Figure 6).

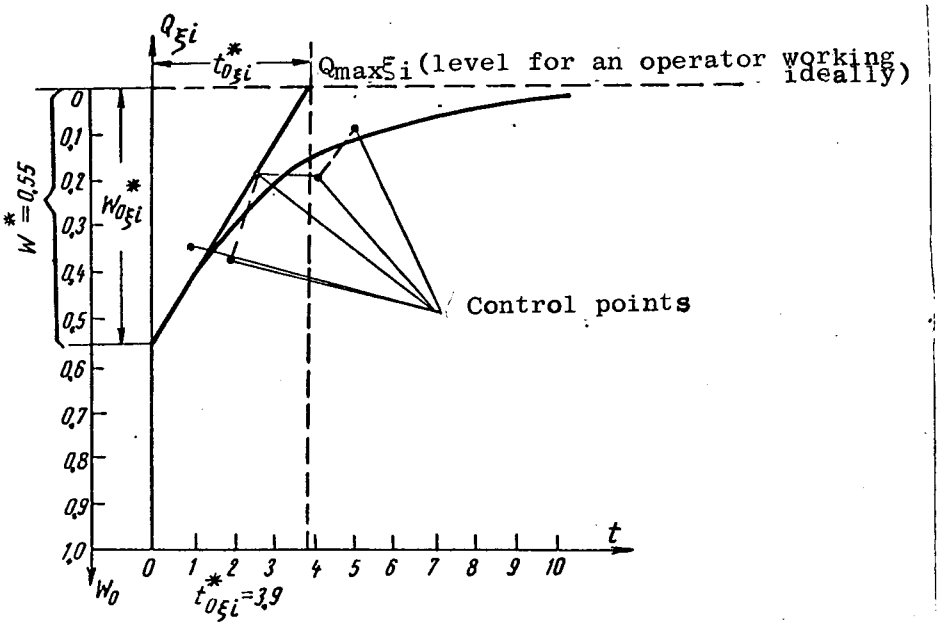

Figure 6. Determination of the values of $W^*_{O_{\xi i}}$ and $t^*_{O_{\xi i}}$.

The condition of achievement by the candidates of a previously established level of job efficiency, Q_{add}, for a specified training time can be used as the basis for the principle of summary classification of the candidates. In this case the candidate is in the category of those fitted for the particular specialty if $t_R \leq T_{add}$, and to that of unfitted if $t_R > T_{add}$. /101

There are many cases when it is possible to establish in advance the time limit for reaching a specified efficiency when a specific training system is used, as well as the so-called optimal training time, T_{opt}, characteristic of personnel with more success in taking the training course (Figure 7). Now it can be considered that a candidate is fitted for a particular specialty if $t_R \leq T_{opt}$, unfitted if $t_R > T_{add}$, and is assigned to the reserve group if $T_{add} \geq t_R > T_{opt}$.

The experimental verification of the selection system discussed is of definite interest. Of 30 men undergoing selection for a job with a sensomotor description, 5 "better" and 5 "worse" were assigned to on-the-job selection.

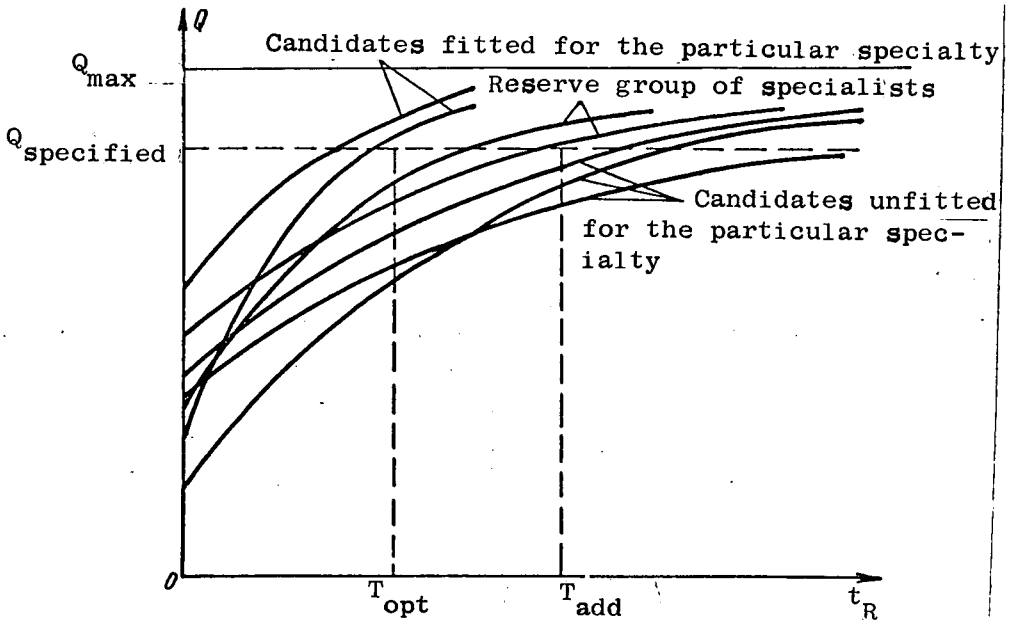

Figure 7. Condition for summary classification of candidates (from results of third stage of selection)

Table 3 lists the results of selection based on tests and on the job performance. /102

TABLE 3. COMPARATIVE CHARACTERISTICS OF THE RESULTS OF SELECTION BASED ON TESTS AND ON THE JOB PERFORMANCE

Candidates (A through J)	Ranking of candidate in accordance with test quality	Original disorder in candidate performance, $W_{O\xi i}$	Coefficient of trainability $\frac{1}{t_{O\xi i}}$	Ranking of candidate in accordance with magnitude of coefficient $\frac{1}{t_{O\xi i}}$	Time spent training candidate to work efficiently, $0.9Q_{max\,\xi i}$	Ranking of candidate in accordance with required training time
A	1	0.93	0.63	1	3.8	1*
B	2	0.5	0.25	5	6.9	4*
C	3	0.97	0.43	3	5.4	3*
D	4	0.94	0.45	2	5.2	2*
E	5	0.7	0.21	7	9.5	6
F	6	0.98	0.23	6	10.4	7
G	7	0.88	0.27	4	8.4	5*
H	8	0.7	0.14	8	14.3	8
I	9	0.53	0.12	10	14.9	10
J	10	0.55	0.13	9	14.5	9

Note: The asterisk marks candidates who pass all stages of selection successfully and are assigned to jobs as operators.

Analysis of the data listed in Table 3 leads to the following conclusions.

Use of proforma tests for selection purposes is sufficiently reliable for purposes of distributing candidates according to psychophysiological indices, and, at the same time, reduces the number of clearly unfitted undergoing on the job selection. The best of the candidates selected on the basis of tests (with the exception of candidate E) also are best from the results of on the job selection. The mean time needed to train these groups of candidates differs by a factor of two.

Comparing ranks from the test results and from the value of the coefficients characterizing the rate of operator trainability, one can evaluate the compatability of the data for the second and third stages of the selection.

Calculation of Spirmen's coefficient of rank correlation, r_S, reveals that /103 in this case $r_{S_1} = 0.83$. The value of r_S is 0.7079 at the significance level of 0.01. In the example considered, $r_{S_1} > 0.7079$, so it can be taken that the ranks of the operators for the particular psychophysiological selection correlates well with the ranks of these same operators established from the results of the evaluation of their capacity to be trained. The correlation coefficient, R_{S_2} is equal to 0.9 if the ranks from test results and from assumed time required to train operators to a level ensuring efficient work, no less than 90% of maximum ($Q = 0.9\ Q_{max}$), are compared. /104

Despite the fact that the time required for on the job selection of candidates can take several hours, and even 25 hours for the more complicated jobs, in some specialties with a sensomotor description, the need to do so is quite evident. It permits the making of the final decision as to the fitness of the particular candidate to work in the specialty based on the evaluation of the anticipated job efficiency and time needed to train the candidate.

Materials obtained during on-the-job selection can be used to construct a scientifically justified system for planning the training process, and forecasting its results.

There is one important aspect associated with the practical use of the

results of vocation selection that should be pointed out. If, as the selection system is developed, there appears to be no way to establish dependable and well verified classification thresholds, the procedure that is developed should not be used for classification, but only for ranking candidates. This changes the purpose of the selection somewhat. Candidates are distributed according to the collected sum of scale values, or according to time required to train them, rather than on the basis of a decision as to the fitness (or unfitness) of candidates for the particular profession.

There is a similar task that arises in cases when the rejection possibility is precluded, and the selection task reduces to separating from a group of candidates those best fitted for assignment to the more responsible jobs.

5. Some Organizational and Procedural Recommendations for Psychophysiological Selection

Personnel found physically fit for training, or for work in a particular specialty should be given a psychophysiological examination. The examination should be conducted by psychologists or engineering psychologists who are thoroughly knowledgeable in the requirements the particular specialty has in terms of the psychophysiological, emotional-volitional, and other qualities of man, as well as who possess the skills required to conduct experimental psychophysiological examinations.

The psychophysiological examination can be collective or individual. Proforma methods are used in the case of the collective examination, for the most part, but film tests, interrogation, and questionnaires too can be used. Equip-/105
ment and proforma methods are used in individual examinations.

On-the-job selection usually is an individual matter. The collective type of selection can be used only when the purpose is to select a group of operators to take care of a particular system (subsystem), but is mandatory after each of the candidates has undergone individual on-the-job selection.

Effectiveness of the selection process depends in large part on observing the conditions necessary for carrying out the process, on the personnel making the selection have a clear understanding of their responsibilities and then carrying them out, and on a number of other organizational measures.

Preparatory Selection Measures

The psychophysiological examination is conducted in specially prepared spaces. Preparing the space involves primarily the creation of required hygienic, esthetic, and production conditions. It should be roomy enough, and predetermined temperature, humidity, and lighting should be maintained, particularly at job sites. Benches should be positioned so the instructor can approach the trainee while he is working, or can observe him at his job site.

The space should contain no objects, instruments, or sources of audible and visual signals that might distract the trainees.

Personnel undergoing selection should be positioned so they will not interfere with each other's performance.

The conditions under which on the job selection is conducted should correspond to the conditions that will prevail during the trainees' future activities. It is recommended that these conditions be made neither more nor less complex because any deviation can cause a considerable distortion in the examination results.

Instructors making the selection should give serious attention to the establishment of the necessary relationship between candidates and the selection process, because this relationship, and therefore the level of their activity in carrying out assignments can influence the selection process, as well as its results.

There are different ways to establish and maintain a positive relationship /106
to the examination and to the necessary level of activity. One of the most dependable ways is to use natural, positive motivation. The essence of the method is to show the candidates the significance of the results of the examination to determine their use in the particular specialty.

Most candidates will develop this positive relationship with the examination if they have explained to them in advance the concept and significance of the examination, in understandable and persuasive form, of course.

The "competitive" motivation, that is, the efforts of the trainee to do the job quicker and better than the others, is quite important. However, this

type of motivation must be used very carefully, and then only in strictly limited situations, dictated by the nature of the assignment.

The nature of the relationship between candidate and examination depends greatly on the behavior and the personal characteristics of the instructor. Confident behavior, an even and helpful relationship with trainees, ability to create a businesslike atmosphere for the job, and active reaction to change in it, all lend themselves to the creation and maintenance of a positive relationship between trainees and the job.

Conducting the Psychophysiological Examination

Establishing the necessary standard background. The "standard background" concept includes the requirements of standardization of the situation, of instruction, and of the form of the examination.

The requirement of standardization of the situation for the experiment is primarily concerned with the external conditions for conducting the examination, particularly with the space in which conducted. Bear in mind that no outside personnel, particularly those who may, because of their position, have an effect on the behavior of those being examined, should be present in the space while the examination is in progress. Conversations and unnecessary moving about in the space, in the operational halls, and the like, should be forbidden. The content and the form of instruction should be constant because even slight changes in the phrasing and construction of the statements can result in a different understanding of the substance of the assignment. Standardization of instruction becomes particularly important in the case of the individual type of selection. If the person giving the examination uses the spoken form of instruction he should learn the text that he will announce, or should read it. Instruction /107 can be standardized if it is reproduced by a tape recorder, or if a printed text is given to those being examined.

Standardization of the form of examination means the observance of constancy of signal parameters (and of their sources) with which those being tested will have to work, of the dimensions, color, type of print, time signals last, their frequency and amplitude characteristics, and the like. This can be done by using standard blanks, instruments, tape recordings. The requirement of stand-

ardization of the form of examination also means constancy of the sequence in which tasks are assigned, time between them, duration of breaks, and the like. It goes without saying that the requirement envisages stability of the structure, duration, and scope of fulfillment of each assignment. This refers in particular to such measures as the conduct of meetings and observations of those being tested. Standardization of form can be achieved in this particular case by the development and use of standard interrogations (questionnaires) and schemes for making the measures indicated.

Special features of conducting a group examination. The group examination must be conducted in a roomy space. Those being examined should be positioned to preclude contact between them. The examination can be conducted with a group of no more than 20 to 25, and it is desirable that it be conducted in the morning.

Once the people are positioned the instructor should familiarize them with the purpose and order in which the work will be done, give them preliminary instructions, which should include the necessity for strict compliance with all commands, to listen with care to special explanations, of how concrete assignments are to be carried out, and for disciplined behavior during the work. The instructor and his assistants observe those being tested and take notes while the assignments are being carried out.

In the case of the group form of on the job selection (when selecting a group of operators) all of the interrelated operations in a complete work cycle should be completed by those persons who, later on, will be working in the same group.

Special features of conducting the individual form of selection. If the algorithm for the future activity of a candidate envisages his working with other operators, the functions of the latter should be performed by a specially trained assistant to the instructor in the process of the on the job selection (if it is impossible to automate these functions). /108

The examinee should not be able to see the actions of the instructor if they provide him with additional information that will simplify his performing the assignment.

Special attention should be given to the candidate's behavior in the individual form of examination. In many cases, an assistant to the instructor, a trained psychologist should be designated for this purpose.

Responsibilities of Personnel Making the Vocational Selection

The size of the group of instructors is determined by the specifics of the selection, the scope of the procedures used, the time limit imposed for the examination, and the like. The group should include a psychophysiologist (or human engineer) and several assistants trained especially to conduct the examination (laboratory assistants, technicians, operators, and others).

The instructor supervises the work of the group, gives instructions and observes those being tested as they do their assignemtns, supervises the processing and analysis of the test materials, makes the decision, and writes the report.

The assistants participate in preparing the job sites, the instrumentation, and the space, make the time study of the assignment, prepare the materials for explaining the next assignment, see that order is maintained in the space while the measures are being carried out, makes sure instrumentation is functioning, and the like. Their responsibilities also include direct participation in processing the materials and in writing the reports.

Making the Decision and Writing the Report

The instructor, or a special commission, determines vocational fitness and makes the decision on the basis of an analysis of the results of the psychophysiological examination and the on the job performance.

The boundary values for the summed indices of the psychophysiological examination characterizing the different degrees of occupational fitness, L_0, the number of gradations of fitness, L_0', L_0'', etc., the permissible values of Q_{spec}, T_{add}, should be determined in terms of the concrete selection tasks, human resources, and requirements in particular specialties. /109

The results of vocation selection lead to the decision of "fit", "unfit", or "forecast indeterminate" (reserve group). Those in the indeterminate group should be given another examination.

Two documents should result from the vocation selection process; an individual selection card, and an alphabetical list of those taking the examination, together with a decision as to group fitness.

Entered on the individual card are the results of how the individual psychophysiological assignments were carried out (test index values), the scale values assigned for completion of each assignment, the total index, values of the parameters t_O, W_O, and t_R, conclusions from the results of meetings and observations, and decision as to group fitness. When necessary, the notes should include justification for a change in group fitness, comments on the status of individual psychophysiological functions, and need for further evaluation of them, training, and the like.

The selection report provides information for the use of commission supervisors (acceptance commissions) and is kept for the period the personnel taking the examination remain on the job (in training).

Particular attention should be paid to seeing to it that the selection results create no false interpretation of the inadequacy of those receiving low evaluations. Poor results indicated for candidates during selection for one group of specialties do not preclude, in fact sometimes even suggest, successful passage of selection by the same personnel for other specialties.

There can be many cases when it is necessary to hold a concluding meeting to explain the selection results, something that will preclude leaving a false impression of the capabilities and performance of those candidates who failed of selection.

6. Fundamental Principles and Conditions for Increasing the Effectiveness of Operator Training

The purpose of operator training is to increase performance efficiency by inculcating definite conceptual models and skills needed if he is to perform quality job operations.

Operator preparation begins with on-the-job selection, when he is made acquainted with the nature of his future job. The next stage of his preparation, of his training, results in providing him with the stable system of skills he needs to meet the conditions of an operator's job. This is done by /110

having the operator do special exercises based on knowledge of the structure of the activities required.

The operator undergoes a sort of internal reconstruction, as it were, during the training process. This reconstruction can be characterized by a transition from high levels of regulation to lower ones as he performs definite operations; that is, by the development of elements of automation. Moreover, as a result of the development and comparison of conceptual models for different and similar situations, the operator reforms the earlier conceptual models he had formed into a higher order model, thus increasing the probability that the operators will make the correct decision in previously unknown or unanticipated situations. The following factors are the primary determinants of the success with which conceptual models and skills are formed, that is of the speed and quality of the training:

correct selection of the set of tasks to be performed during training;
the effectiveness with which the training process is controlled;
the effectiveness with which teacher monitors pupil's actions.

Working conditions for real systems usually can be changed within quite broad limits. This requires the corresponding reaction on the part of the operator, something that is included in the adequate "switching" of previously formed skills. Here the first thing that must be done is to evaluate the approximate complexity of the operator's work on a concrete job in a real system in order to correctly solve the problem the operator is learning [2].

No procedures have yet been devised that provide a sufficiently quantitative evaluation of the complexity of a particular type of operator activity.

The following functional provides a known degree of approximation of the complexity of operator activity

$$\vec{K} = \vec{F}(\vec{K}_S, \vec{K}_V, \vec{K}_L, \vec{K}_R, \vec{K}_O, \vec{T}), \tag{7}$$

where $\vec{K}_S, \vec{K}_V, \vec{K}_L, \vec{K}_R, \vec{K}_O$ are the indices characterizing, respectively, the complexity of the structure of the information model, K_S, conditions for perception and processing of input information, K_V, the heuristic

(logical) activity, K_L, the operator's motor activity, K_R, and /111
the structure of the object, or process, controlled, K_O;
$\vec{T}$ is the index of the psychophysiological stress placed on the operator, and depends on the complexity of the operations he is performing, stress reactions, environmental conditions, and the like.

Despite its known conditionality, Eq. (7) is convenient to present by using binary separation of the components of its factors on the basis of the "simple-complex" principle. The notation for the index of complexity then will be a combination of the "S-C" ("Simple-Complex") evaluations, depending on the concrete type of operator activity. For example, the set of the simplest conditions can be presented in the form

$$\{S_S, S_V, S_L, S_R, S_O, S_T\}.$$

The action of an operator picking out the coordinates of a moving target against a background of radio interference for subsequent input to a computer can be described as follows when this approach is taken

The complexity of the action taken by an operator assigned to semiautomatic tracking systems (with compensator tracking and complex dynamics of the target being controlled under favorable conditions for the perception of the error signal) can be evaluated thus

and so forth.

These characteristics obviously can be used as an approximate, partial estimate of the complexity of the operator's job for concrete system working conditions.

The selection of a set of tasks must take into consideration the fact that significant variations in conditions within the limits of their possible range not only will reduce speed, but quality of training as well. This is so primarily because the presentation of a multiplicity of tasks invokes in the trainee the formation of the corresponding multiplicity of conceptual models, which

not only remain incomplete because of the limited capabilities of the subject and the limited training time, but even "distract" his attention, making it more difficult to grasp the overall reasoning for his own actions, the development of behavior patterns, and the like. /112

The number of tasks can be reduced if it is possible in the first approximation to group the original data in such a way that each group corresponds to a definite conceptual model.

Now the total number of tasks in the first stage of training will correspond to the required number of conceptual models and Eq. (7) can be written in the form of a conventional matrix

$$\vec{K} = \begin{vmatrix} K_{S_1}, K_{V_1}, K_L, K_R, K_O, K_{T_1} \\ K_{S_2}, K_{V_2}, K_{L_2}, K_{R_2}, K_{O_2}, K_{T_2} \\ \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\ \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\ K_{S_n}, K_{V_n}, K_{L_n}, K_{R_n}, K_{O_n}, K_{T_n} \end{vmatrix} \quad K_{ji} = \begin{vmatrix} S_{ji} \\ C_{ji} \end{vmatrix}$$

We then can obtain improvement in the conceptual models within the range of change in external factors expected in practice by varying the conditions for the tasks within the limits of each group.

The efficiency with which the selected tasks are mastered (completed) by the trainee depends, as has been pointed out, on the organization of the training process, that is, on the forms and methods adopted for using the training information.

The selection of some one form of training is governed by the specific features of the concrete operator activity, primarily its complexity.

But regardless of the specifics of the activity, the organization of operator training, regardless of vocation, should:

provide the necessary level of motivation;

provide for a rational time distribution of the set of tasks;

create conditions for positive skill transfer,[7] and avoid the causes /113

[7] Positive skill transfer is the result of successive training in a set of activities during which skills learned earlier favor the formation of subsequent ones.

for the occurrence of the phenomenon of the negative transfer[8] and skill interference;[9]

create conditions for intelligent mastering of the training information;

use the oral algorithm (verbalization) while forming the conceptual model;

provide for timely delivery of feedback to the trainee on the quality of his work.

There is no need to dwell on the above principles, but there are a number of more important features that influence training effectiveness that should be emphasized.

What must be borne in mind, in particular, is that activeness on the part of trainees can be achieved primarily by intelligent motivation, taking into consideration their individual characteristics, interest in mastering the particular specialty, the "emotionalism" involved in the training process, sense of competition, and others.

A marked improvement in training effectiveness is observed when the sequence in which the tasks are presented to the trainee take into consideration the possibility of positive skill transfer along with movement from simple to complex. Practically speaking, this can be provided for by arranging the tasks so that each preceding task led to the formation of elements of the conceptual model, or skills, having some degree of commonality with the model and skills taking shape during each succeeding task.

Conditions conducive to the occurrence of skill interference, such as poor explanation of the material, going on to a new task before the preceding one has been sufficiently mastered, and the like, must be reduced to a minimum when drawing up the training program and procedures, as well as in the training process. Conditions conducive to negative skill transfer present a similar danger.

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[8]Negative transfer is the result of successive training in a set of activities during which skills learned earlier have a negative effect on the formation of subsequent ones.

[9]Skill interference is a phenomenon interfering with successful training, and occurs when the trainee is presented with similar tasks requiring different methods for their accomplishment.

Bear in mind that the interference and negative skill transfer phenomena /114 are concealed, usually putting in an appearance in the form of extended training, something that sometimes is mistakenly interpreted as the result of the unsuitability of the trainee for the particular type of activity.

Note that training is more rapid, and positive skill transfer is more complete, if the trainee understands the principles of the actions taken. However, correct comprehension of principles does not always guarantee that they will be used in time in the corresponding situation. This requires that the trainee be taught how to analyze and find the common characteristics of the former and the new situations.

The chief difficulty arising in training operators is the contradiction between speed and accuracy in performing the operation. In this regard, it is very important that rigid requirements for accuracy of performance be avoided at the beginning of the training, but rather to try to get the trainee to do the particular operation correctly as soon as he has clearly mastered the sequence of necessary actions in each concrete situation. Only then should attention be turned to achieving the required accuracy, and then only doing the operations slowly.

If an increase in tempo upsets the nature of the action taken by the trainee it is necessary to try first of all for faultless performance of the operations at the specified speed, and accepting a temporary reduction in accuracy.

The "trial and error" method [19] is the one most often used during the training process in the case of operators with a predominance of complex components of sensory activity, C_S, C_L, C_V, C_T, requiring the processing of a considerable quantity of information under unfavorable information perception conditions, as well as for operators in a heuristic vocation carrying out such complex logic operations as complex information evaluation, of decision making.

The most substantial gain in time and speed of formation of skills is observed when the actions of the trainee, as distinguished from the conventional "trial and error", are based on an intelligent selection of the optimum decision. This method, unfortunately, still has not received the necessary theoretical development, something that makes its practical utilization difficult.

Significant success in reducing training time, and in increasing the effect-/115
iveness of training, can be achieved by timely and clear presentation to the trainee of information on the results of his actions. Delaying this information makes difficult, and now and then generally precludes timely active reaction by the trainee to his mistaken, or inaccurate, actions. The trainee should be presented with information characterizing the process of change in the parameters of the target he is controlling relative to their permissible values when the nature of the action is a continuous one, or by a "true-false" signal if discrete, and not with a summary evaluation of his work.

The use of an aural analyzer for reception by the operator of information on the quality of his work has proven extremely effective in the case of visual perception of signals.

The summary evaluation, which is of importance primarily for motivating the actions of the trainee, usually is given to him after he has completed the cycle of actions.

The continuous presentation of feedback can distort the process of shaping the necessary conceptual model, and this must be considered. Feedback therefore is supplied in accordance with the absence of external (additional) artificial stimuli (signals) under real conditions of operator activity. Training sessions using feedback therefore should be held periodically, and then curtailed as trainee errors decrease.

Experimental research has shown that supplying the trainee with momentary information at this stage of training is psychologically justified, particularly when perception conditions are complex, and increases the rate of shaping the corresponding skills by a factor of 4 to 5 (Figures 8, 9).

Quality of training is greatly dependent on timely reaction on the part of the teacher, during the training period, and this, in turn, depends on the quality of the monitoring system used as the trainees accumulate knowledge and form skills.

These principles of increasing the effectiveness of skill formation are applicable as well to the conditioning stage. The use of feedback is something of an exception. There is the view that at the conditioning stage one should

resort to prompting only when there is a marked increase in operator errors because of complication of the conditions under which the actions are taken, or after long breaks in the work.

/116

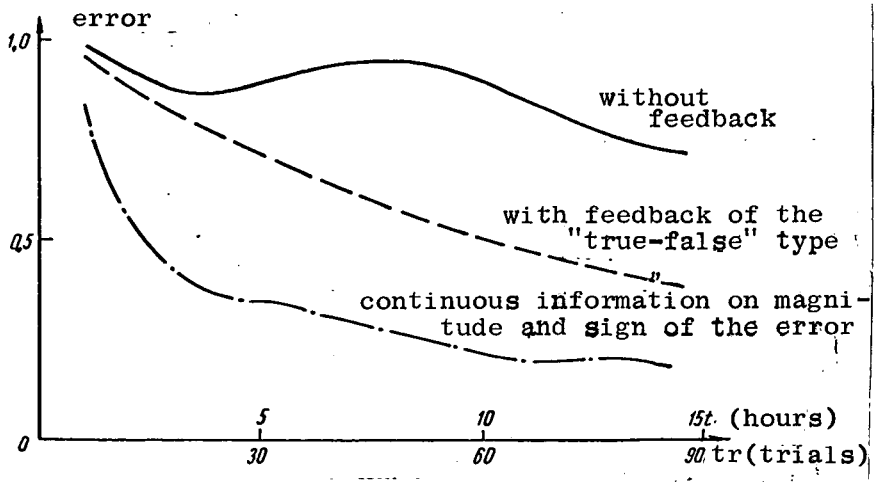

Figure 8. Reduction in level of errors by trainnee in terms of type of feedback.

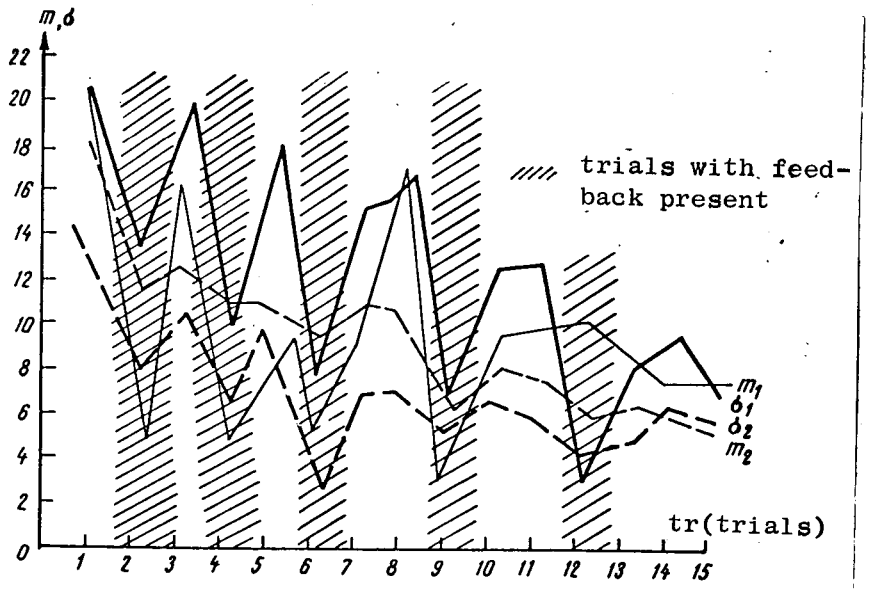

Figure 9. Reduction in level of systematic, m, and random, δ, components of errors made by operators supplied with continuous information in terms of magnitude and sign of error.

7. Influence of Special Physical Conditioning on Effectiveness of Operator Training

/117

The level of development of man's most important physical attributes (strength, speed, endurance, and the like) is more important for the successful performance of unautomated jobs. Still, the problem of special physical conditioning as a means of increasing the quality of vocational training arose with the appearance of vocations with an operator job description.

This can be explained on the one hand by the fact that in nonautomated production the connection between the level of physical conditioning and the results of job performance are more obvious and unambiguous. A weak hammer man in a forge shop, for example, would be useless.

On the other hand, a vocation requiring great strength, endurance, and speed in actions, itself has a conditioning effect on the development of these attributes. Therefore, under conditions such as these, physical fitness can be increased, or held at a level optimum for doing the job, without special physical exercises.

The specialist with an operator's job description usually has a job without significant physical overload. The motor activity of the operator is reduced when he is on the job. This eliminates the conditioning effect the unautomated job has on the muscular and cardio-vascular systems.

At the same time, the increase in nervous and emotional stress accompanying most of the actions taken by the operator on the job put heavy loads on his cardio-vascular system. Tests conducted with subway motormen have shown that any of their controlling actions cause a definite change to take place in the frequency of heart contractions, and, according to electrocardiograms, a preemergency situation will cause particularly unfavorable changes in the performance of the cardio-vascular system. Similar reactions can be observed among pilots, radiotelegraphers, dispatchers working in the different modes of transportation, and others.

Individual changes in the rhythm of the cardio-vascular system taking place against a background of reduced metabolism as a result of "motor hunger" that is part of the job has a particularly unfavorable effect on operator

health. Special physical conditioning for the operator should be concerned /118
primarily with solving the problem of increasing the overall conditioning of the organism, its resistance to unfavorable effects of the production environment.

At the same time, the operator's vocation often imposes increased requirements on the level of psychophysiological and motor qualities. They are very high in many cases, so selecting candidates for vocations without consideration of the corresponding physical attributes required by the vocation will have negative results. It is true that the operator can develop most of the necessary qualities during his vocational development, and this can be confirmed by testing different specialists with an operator's job description with long production experience. This approach to the development of important vocational qualities is a very long one, however, and depends greatly on the overall physical attributes of the operator.

Moreover, many psychophysiological qualities, such as reaction speed, attention features, motor memory, and the like, are very difficult to add to the training, and if operator conditioning is accelerated it becomes impossible to reach a high level of development of these qualities using nothing other than vocational conditioning methods.

Special physical exercises can help considerably in acquiring the necessary level of development of psychophysiological qualities.

The inclusion of physical exercises designed to eliminate shortcomings in the development of attention, motor memory and movement coordination in the overall system of training flight school students, has made it possible for students to solo much sooner than those who did not do the exercises.

At the basis of the effect of physical conditioning on the success of the overall training is the phenomenon of the transfer of motor qualities and skills acquired in participating in sports to the mastery of another type of drill. Bear in mind that the transfer of motor skills and qualities can have a positive, as well as negative effect. Operator training therefore must consider the behavior patterns that make possible the positive transfer of motor /119
skills and qualities to vocation activity.

The task of thoroughly conditioning the organism can be carried out by resorting to different types of sports, because the transfer in such case is made on the basis of vegetative changes occurring in the organism as a result of physical conditioning. Numerous tests have confirmed this postulation [6, 8].

Physical conditioning practice indicates that the development of such physical qualities as strength, speed, and endurance, within the limits needed by the operator to do his job successfully, can take place in very short periods of time (20 to 24 hours of drills). At the same time, the development of special motor skills and dexterity requires long, painstaking work.

Physical conditioning of the operator, therefore, should be directed at mastering a wide range of motor skills. The wider the range, the easier it will be to derive the rational motion needed to master the vocation of operator. For example, of 800 men being trained to be operators, those with many of the skills acquired in sports, rowing, bicycling, and the like, were more successful in mastering the training. At the same time, the difference between groups with a different number of motor skills were greater than they were between groups with different levels of sport training.

Characteristic of the highly trained sportsmen was less wasted motion. They used precise strength amplitudes and magnitudes. The same is characteristic of experienced specialists with an operator's job description. Tests conducted with pilots and radiotelegraphers revealed that motor reaction time reduction among them was not the result of the reaction's latent period, but rather the result of the motor component, so their total reaction time was much shorter than was that of persons without this training. Tests of sportsmen also showed that while there was little difference in the reaction's latent period, there was a considerable difference in the magnitude of the motor component as compared with the others that were tested. The more athletic training, the smaller the mean magnitude of the motor component because of less scatter in individual reactions. This considerably improves the accuracy of the oper- /120
ator's work.

However, there are some cases where the drills done for certain types of sports develop qualities or motor skills that interfere with mastering important vocational qualities. So before some particular sport is recommended, a

comparison must be made between the psychophysiological and motor qualities characteristic of the particular operator activity and those that are developed and strengthened by various of the physical exercises.

Pilot success and the practice of deductions for student pilots was analyzed. This resulted in all types of sports being broken down into three groups: those lending themselves to the acquiring of pilot qualities, those deemed indifferent, and those developing qualities unfavorable for pilot activities. The first group includes basketball, swimming, including underwater, while the third includes boxing, field events, and gymnastics. The unfavorable effect of boxing is the result of constant stress attributable to anticipation of being hit, and that of fielf events to the disproportionate application of strength to the hands for control. Characteristic of gymnasts is the development of a capability for performing large amplitude movements, something that is not needed to fly an airplane. Basketball players get accumtomed to rapid changes in conditions, and this enables them to develop the ability to distribute their attention, one of the foremost psychophysiological qualities in piloting. Equally important is the ability to orient oneself in space, something that is developed in underwater swimming. Swimming for sport helps relieve stress.

Heavy involvement in field events and gymnastics also is counterproductive for radiotelegraphists because neither develops mobility in the radiocarpal joint because of the increase in the strength of the muscles for flexing the wrist. The mobility of dorsal-palmar flexure of the radiocarpal joint by man usually is $106^{\circ}$to 108°. This increases to 119° to 120° after nine months of working with radiotelegraphic equipment, and is as much as 145° to 150° among experienced radiotelegraphers. The higher orders of change in mobility of the joint do not occur among gymnasts and javelin throwers. Basketball and volley ball players have a mobility factor of between 124° and 125°.

These examples indicate the importance of specialization in physical conditioning for operators. Knowledge and use of the behavior patterns of such specialization will result in better training in short periods of time. /121

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CHAPTER 4

OBJECTIVE MONITORING OF THE LEVEL OF TRAINING OF OPERATORS IN THE "MAN-MACHINE" SYSTEM /123

1. The Role and Place of Objective Monitoring in the Operator Training System

Any training system requires continuous monitoring of its results. The principal task of such monitoring is to obtain data needed to arrive at an objective judgment of the success attained by an operator taking the training course, and to evaluate the anticipated effectiveness of his work. Monitoring of the degree of training of the operator should anticipate monitoring the results of his work, as well as monitoring the changes that take place in his psychophysiological characteristics. This latter is a comparatively new requirement in the practice of training, and requires some explanation.

In physiology the process of shaping a motor skill is considered to be the gradual "freedom" of the higher nervopsychic centers of the regulation function, with the help of which an action is performed, and the transfer of this function to a simpler, lower nerve mechanism. This is achieved by automating the skill. Therefore, complete characterization of the process of shaping a skill requires an objective consideration of the process involved in the reconstruction of the factors for the operator's nervopsychic sphere. Experience from electrophysiological research shows that physiological characteristics have an independent, and important, value as skill shaping factors. Although this has been known for a long time, the practical accomplishment of objective monitoring of physiological characteristics has always run into difficulties /124 (if not technical ones, then those associated with the interpretation of the data obtained).

Two evaluation methods, based on work results, are widely used to monitor the training the operator has received:

in terms of standards;

in terms of the results of a comparison between the algorithm for the work of the operator being monitored, and the algorithm for the work of an operator known to have been trained under the same conditions.

The first method is simpler and more graphic, but its use is made difficult by the complexity of the scientific justification for the standards (boundary limits for the evaluations).

The essence of the second method is this. A correctly organized training process allows the operator to formulate a more economical algorithm of activity, reducing to a minimum the number of controlling actions. This is why the number of controlling actions in a unit of time for identical control quality sometimes is taken as the index of operator training. Figure 1 shows oscillograms of the object control process for two operators. Note that both operators exercised the required control quality and obtained approximately the identical evaluation in terms of the integral index λ . However, in the case of the first operator, the number of dips in the control parameter curve is approximately twice the number for the second, so the second operator is better trained than the first because his work algorithm is more economical.

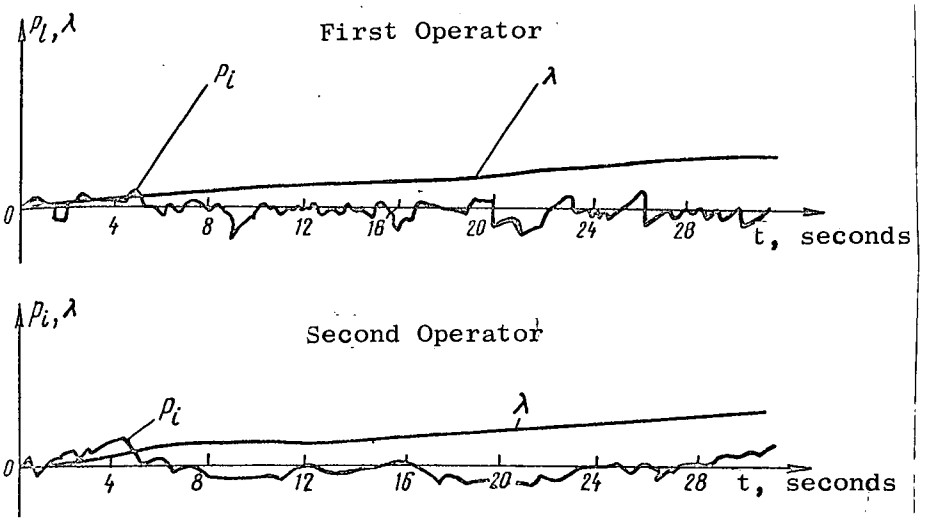

Figure 1. Oscillograms of the object control process for operators with different levels of training.

Let us formulate the basic requirements imposed on a monitoring system. Monitoring should be:

operative; that is, its results should be fed into the corresponding channels as quickly as possible, and should be practically immediate over the answering and feedback lines;

rational; that is, include only those links that carry information needed to do the tasks assigned;

graphic, from the point of view of results; that is, be capable of repeated and graphic reproduction of the recorded results;

objective.

Objective monitoring can be achieved by the unconditional satisfaction of such conditions as:

the use of indices providing an objective evaluation of the factors /125 subject to monitoring;

documentation of data needed to calculate the selected indices;

automation of the processes of recording, processing, and analyzing the data obtained.

The systems of indices for evaluating the level of training, and the algorithms for calculating them, are reviewed below. The methods for the technical realization of a monitoring system meeting the requirement imposed are reviewed in Chapter 7.

2. Selection and Justification of the Indices for Evaluating Operator Training Level.

Evaluation of the level of vocational training of an operator from the results of his work is based on an analysis of a number of parameters characterizing the intermediate and final stages of his completion of his functional duties.

The indices usually subject to analysis are random magnitudes, the distribution laws for which in many cases are not known in advance. One sometimes /126 must resort to oversimplification, the more so because analysis of several of the interrelated parameters is difficult for procedural and technical reasons.

The mean value (the mathematical expectation) of some monitored parameter often is taken as the basic index for evaluating operator training level.

Is this approach a fair one? Let us, as we monitor operator A, obtain a series of values for the selected index of his preparedness, x_1, x_2,...,x_n. The distribution of the monitored parameter is shown in Figure 2a, where m_{xA} is the mathematical expectation of monitored magnitude x_i. This same figure

shows the distribution for the same parameter for operator B. As we see, $m_{xA} < m_{xB}$, so the quality of the work done by operator A, evaluated in terms of the value m_x, is higher than that of the work done by operator B, despite the fact that the higher level of training of the first operator is not evident. The conclusion as to the identical levels of training of operators A and B shown in Figure 2b is erroneous.

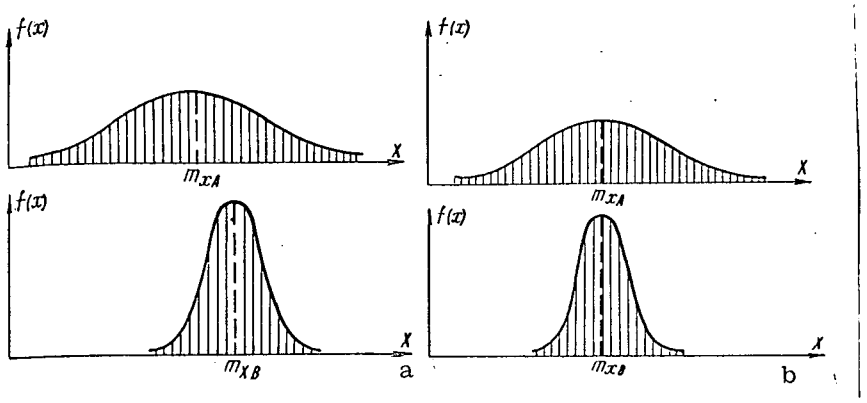

Figure 2. Distributions of index of quality of the work of operators A and B.

The level of operator training can be evaluated by the effectiveness of his work, understanding the term to mean the degree to which the results of his work correspond to the assigned task.[10]

The analytical expressions for evaluating the probability of performing the task differ in each concrete case, but often are functions of two magnitudes; mathematical expectation, and dispersion of the measured parameter.

Let P(m, D) be the probability of performing the task with mathematical expectation m and dispersion D of the monitored parameter. Let us consider some possible analytical expressions for P(m, D) functions.

It is known that in practice the accuracy and time characteristics of the operator's work is subject to evaluation. If, for example, it is proposed that the accuracy with which the operator is tracking the pip be evaluated, the probability that the operator's cursor is off the center of the pip in one coordinate by a magnitude not in excess of t can be taken as the function /127 P(m, D) [4]. In this case, for distribution in accordance with a normal law,

[10] The term "assigned task" is understood to mean any set of functions performed by the operator.

the tracking error for each coordinate[11] will be

(1)

We will take it that the accomplishment time is a random magnitude subordinate to the so-called alpha-distribution [6] in our evaluation of the quality of the work done by the operator in terms of time to perform the individual operations. Selection of this distribution is based on the following principles. It is considered that the productivity of labor, B, is convenient to calculate as a random magnitude distributed in accordance with a normal law. Assuming that B is constant during the time it takes to perform the work, we can approximate the process of its realization, W(t), by a random function of time

$$W(t) = Bt \quad . \tag{2}$$

The time to perform work of scope ω also can be taken as a random magnitude, and this we can find through the expression

$$T = \frac{\omega}{B} \quad . \tag{3}$$

/128

There is an upper, b_2, and lower b_1, limit of the magnitude B, so the truncated normal low

$$f(B) = Cf(B) = \frac{C}{\sigma_b \sqrt{2\pi}} \exp\left[-\frac{(B-m_b)^2}{2\sigma_b^2}\right] \tag{4}$$

must be considered as its distribution law when $b_1 \leq B \leq B_2$, where m_b and σ_b are the mathematical expectation and dispersion of the magnitude B, respectively, and c is a norming factor.

What follows from Eqs. (3) and (4) is that the time to do the job has a probability density function

$$f(t) = Cf(t) = \frac{C\omega}{\sigma_b t^2 \sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{\omega}{\sigma_b t} - \frac{m_b}{\sigma_b}\right)^2\right] \tag{5}$$

when $t_1 \leq T \leq t_2$, where $t_1 = \frac{\omega}{b_2}$, $t_2 = \frac{\omega}{b_1}$.

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[11] There are similar expressions for other distribution laws.

Introducing the designations $\beta=\frac{\omega}{\sigma_b}$, and $\alpha=\frac{m_b}{\sigma_b}$, we obtain an expression corresponding to the alpha-distribution

$$f(t)=\frac{C\beta}{t^2\sqrt{2\pi}}\exp\left[-\frac{1}{2}\left(\frac{1}{t}-\alpha\right)^2\right], \tag{6}$$

where

α is a dimensionless coefficient (the relative mean productivity of labor);

β is the relative volume of work (it has the dimensionality of time).

Practice often takes $C \approx 1$, and an alpha-distribution of the following type is used

$$f(t)=\frac{\beta}{t^2\sqrt{2\pi}}\exp\left[-\frac{1}{2}\left(\frac{\beta}{t}-\alpha\right)^2\right]. \tag{7}$$

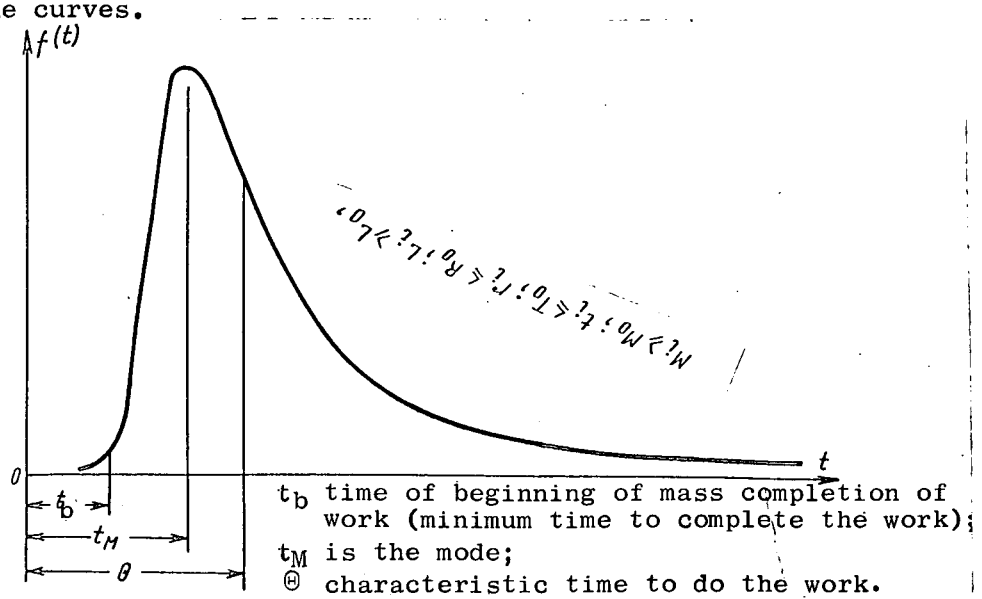
Another form can be used

$$f(t)=\frac{\alpha}{t^2\sqrt{2\pi}}\exp\left[-\frac{\alpha^2}{2}\left(\frac{\theta}{t}-1\right)^2\right], \tag{8}$$

where $\theta=\frac{\beta}{\alpha}=\frac{\omega}{m_b}$

is the characteristic time for doing the job, approximately equal to the alpha-distribution median.

Figures 3 and 4 show the characteristic alpha-distribution points and the shape of the curves.



t_b time of beginning of mass completion of work (minimum time to complete the work);
t_M is the mode;
θ characteristic time to do the work.

Figure 3. Typical shape of curve and characteristic alpha-distribution points.

/129

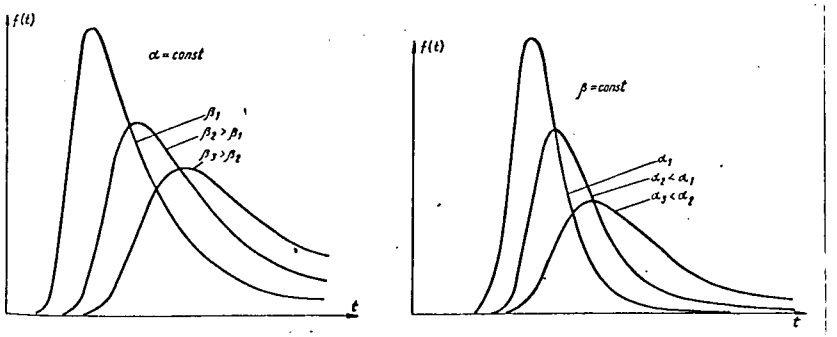


Figure 4. Influence of the parameters α and β on the type of distribution curve.

Thus, the function P(m, D) will take the following form in the case of an alpha-distribution of the parameter being monitored providing that the job is done in a time frame not exceeding T

$$P = \int_0^T \frac{\beta}{t^2\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\beta}{t}-\alpha\right)^2} dt = \frac{1}{2}\left[1-\Phi\left(\frac{\beta}{T}-\alpha\right)\right]. \quad (9)$$

Since the determination of the parameters α and β from statistical test materials requires time-consuming calculations, it is desirable to introduce the magnitude /130

$$X = \frac{1}{t}, \quad (10)$$

distributed in accordance with a normal law.

Then

$$P(m_X, D_X) = \frac{1}{2}\left[1-\Phi\left(\frac{\frac{1}{T}-m_X}{\sqrt{D_X}}\right)\right], \quad (11)$$

where

m_X, D_X is the mathematical expection and dispersion of the random magnitude X, respectively.

The analytical Eqs. (1), (9), and (11) can serve as the indices of operator efficiency on the job when the latter is evaluated by the probability of doing the job for known monitored parameter probability density functions.

Let us consider the variant when the readiness of the operator is evaluated by results of analysis of indices with a previously unknown parameter probability density function. A characteristic example of this type is monitoring the

actions of an operator in an anti-aircraft defense system in tracking an enemy flight [1, 5]. In this case it is desirable to understand that the probability of destroying at least M_0 targets of M targets participating in the flight is the probability that the operator in the anti-aircraft defense system is doing his job: $1 \leq M_0 \leq M$.

The probability that the job is being done also can be understood to mean:

when time characteristics are evaluated: the probability of performing the i^{th} operation (in the overall work cycle) in time t_i, not exceeding a specified T_0;

when accuracy characteristics are evaluated: the probability of performing the operation with errors r_i, not exceeding a specified magnitude R_0;

when correctness of the decision made is evaluated: the probability of making at least L_0 error-free decisions of L made during the performance.

In accordance with these indices, the process of calculating the probability of doing the job involved a determination of the relationship of the number of favorable events, in which

(12)

to the total number of observations made to monitor the parameter.

It is, therefore, desirable, in many cases, to take the probability that /131 the operator will do the job assigned as the index of effectiveness of operator performance.

The use of an index based solely on analysis of mean values, or on the dispersion of the magnitude measured, is desirable for solving only those problems in which the mean value, or dispersion, remains unchanged.

3. Possible Monitoring Variants and the Mathematical Apparatus for Evaluating the Quality of the Work done by Operators

Two types of analytical expressions for evaluating the probability that the operator would do the job assigned were reviewed in the foregoing. The first is based on the use of information on the distribution law for the measured magnitude, the second requires knowledge of the number of favorable events only

$$K(M_i \geq M_0).$$

A number of calculations must be made for practical calculations of the first variant. So far as evaluating performance accuracy through Eq. (1) is concerned, these calculations reduce to finding the magnitude P through the formulas

$$\left.\begin{aligned} m_y &= \frac{1}{n}\sum_{i=1}^{n} y_i \\ D_y &= \frac{1}{n-1}\sum_{i=1}^{n}(y_i - m_y)^2 \\ P &= \frac{1}{2}\left[\Phi\left(\frac{l-m_y}{\sqrt{D_y}}\right)+\Phi\left(\frac{l+m_y}{\sqrt{D_y}}\right)\right], \end{aligned}\right\} \tag{13}$$

where

y is the monitored parameter;

m_y, D_y are mathematical expectation, and dispersion, of the monitored parameter respectively;

$$\Phi(X) = \frac{2}{\sqrt{2\pi}}\int_0^X e^{-\frac{t^2}{2}}\,dt.$$

The values of x_i, m_X,, D_X, and P should be found in advance when time characteristics are being monitored in accordance with Eq. (11):

$$\left.\begin{aligned} x_i &= \frac{1}{t_i} \\ m_x &= \frac{1}{n}\sum_{i=1}^{n} x_i \\ D_x &= \frac{1}{n-1}\sum_{i=1}^{n}(x_i - m_x)^2 \\ P &= \frac{1}{2}\left[1-\Phi\left(\frac{\frac{1}{T}-m_x}{\sqrt{D_x}}\right)\right] \end{aligned}\right\} \tag{14}$$

/132

The probability of doing the job, P, is quite simple to find for practical calculations for the second variant. It is the ratio of number of appearances of favorable outcomes to total number of events, N

$$P = K/N.$$

From the standpoint of simplicity of the calculations, therefore, there is no doubt as to the advantage of the second variant.

Let us consider both variants for evaluating the effectiveness of operator job performance based on the "pass-fail" principle from the standpoint of the need for number of observations for these purposes.

The evaluation of operator job effectiveness for the second variant can be linked with the probability that he will do his job in the following way. The operator is given a "pass" if $P > P_1$, and a "fail" if $P < P_0$.

When $P_0 \leq P \leq P_1$, there is no way to evaluate operator performance unambiguously, so the latter can be given either a "pass" or a "fail".

The evaluation of the operator's performance can be increased (α) or decreased (β) .

If α and β are the probabilities of the errors already mentioned in evaluating by the "pass-fail" principle, P_0 and P_1 are known, the task reduces to selecting the values $P_*(P_0<P_*<P_1)$ and the number of experiments, n, during which the operator would be given a "pass" if $P > P_1$ and a "fail" if $P < P_1$.

Considering the fact that when $n \cdot P_0 > 4$ and $n(1 - P_1) > 4$, the approximate probability that the job will be done, determined by a limited number of experiments, can be the distribution in accordance with a normal law with dispersion $P(1 - P)/n$. Accuracy will be adequate for practical use and the values of P_* and n can be found through the following system of equations [4]:

$$\left.\begin{aligned} \int_{-\infty}^{P_*} f(p, P_0, n)\,dp &= 1-\alpha \\ \int_{-\infty}^{P_*} f(p, P_1, n)\,dp &= \beta , \end{aligned}\right\} \qquad (15)$$

/133

where

$$f(p, P_i, n) = \frac{1}{\sqrt{\frac{2\pi P_i(1-P_i)}{n}}} \exp\left[-\frac{(p-P_i)^2}{\frac{2P_i(1-P_i)}{n}}\right]; \qquad (16)$$

$i = 0, 1.$

The number of observations needed to determine the evaluation with specified dependability can be found through the formula

$$n = \frac{[\Psi(1-\alpha)\sqrt{P_0(1-P_0)} - \Psi(\beta)\sqrt{P_1(1-P_1)}]^2}{(P_1 - P_0)^2} . \qquad (17)$$

Any of the following expressions can be used to find P_* [3]:

$$\left.\begin{aligned} p_* &= p_0 + \Psi(1-\alpha)\sqrt{\frac{p_0(1-p_0)}{n}} \\ p_* &= p_1 + \Psi(\beta)\sqrt{\frac{p_1(1-p_1)}{n}}\ , \end{aligned}\right\} \tag{18}$$

where

Ψ is a function, the inverse function $\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{x} e^{-\frac{t^2}{2}}dt$.

Time-consuming operations are required to find the analytical expression for evaluating the required number of observations when the first variant is applied to monitoring the effectiveness of operator performance.

An asymptotic evaluation of the required number of experiments reveals that approximately 35% fewer observations are needed to obtain the same dependability of evaluation for the first variant than is the case for the second (when $\alpha \approx \beta$.).

These facts show the need to find new methods for analyzing statistical data that will reduce the number of observations without reducing the dependability of the evaluation. Successive analysis [2] can be one such method. The number of observations is not fixed in advance when this method is used. One of two decisions is made in order to evaluate the effectiveness of operator performance after each observation: give a definite evaluation, or continue the check.

The advantages of the successive analysis method, as compared with the /134 once-through selection method, increase with reduction in α and β, that is, with increase in the requirements for dependability of evaluations.

The determination of the probability that the operator will do the job according to the relative number of favorable results, Eq. (12), is made as follows.

Let P be the probability of doing the job characteristic of the particular operator, and y_i be the result of the observation ($y_i = 1$ if the i^{th} observation satisfies the system of inequalities of Eq. (12), otherwise $y_i = 0$). These two magnitudes, P_0 and P_1, now can be selected such that the evaluation

"fail" was assigned when $P < P_0$, and "pass" when $P > P_1$, but the probability of increasing or decreasing the evaluation in this case should not exceed the assigned values α and β.

The probability of obtaining the sample $y_1, y_2, \ldots, y_m$ with K favorable outcomes, $y_i = 1$, will equal

$$p^K (1-p)^{m-K}, \tag{19}$$

where

K is the number of favorable outcomes as a result of m observations.

If $P = P_0$, then

$$P_{0,m} = p_0^K (1-p_0)^{m-K}. \tag{20}$$

If $P = P_1$, then

$$P_{1,m} = p_1^K (1-p_1)^{m-K}. \tag{21}$$

After certain transformations, we obtain the following expressions for determining the evaluation bounds

$$a_m = \frac{\ln \frac{\beta}{1-\alpha}}{\ln \frac{p_1}{p_0} - \ln \frac{1-p_1}{1-p_0}} + m \frac{\ln \frac{1-p_0}{1-p_1}}{\ln \frac{p_1}{p_0} - \ln \frac{1-p_1}{1-p_0}}, \tag{22}$$

$$r_m = \frac{\ln \frac{1-\beta}{\alpha}}{\ln \frac{p_1}{p_0} - \ln \frac{1-p_1}{1-p_0}} + m \frac{\ln \frac{1-p_0}{1-p_1}}{\ln \frac{p_1}{p_0} - \ln \frac{1-p_1}{1-p_0}}. \tag{23}$$

If /135

$$K \leq a_m, \tag{24}$$

the operator receives a "fail".

If

$$K \geqslant r_m , \tag{25}$$

the operator receives a "pass."

If

$$r_m > K > a_m , \tag{26}$$

the check continues.

Since a_m and r_m depend solely on the magnitudes P_0, P_1, α, and β, they can be calculated and tabulated in advance.

The linear dependence of a_m and r_m on m results in the use of a quite simple monitoring method that utilizes evaluation graphs (Figure 5).

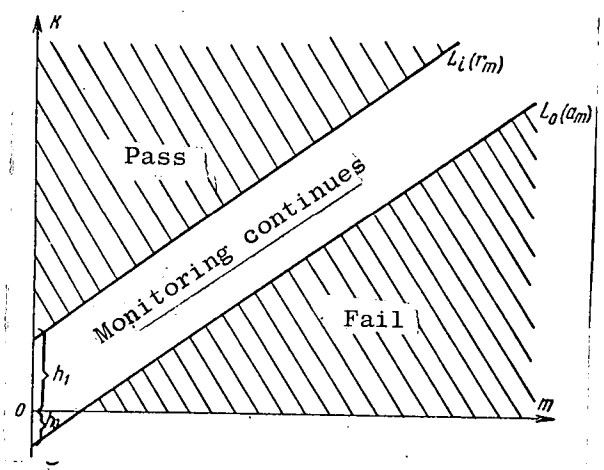


Figure 5. Graphic monitoring method using sequential analysis.

Two parallel lines, L_1 and L_0, are constructed within the K, m system of coordinates with angular coefficient common to them

$$S = \frac{\frac{1-p_0}{1-p_1}}{\ln\frac{p_1}{p_0} - \ln\frac{1-p_1}{1-p_0}} \tag{27}$$

and with points of intersection with the vertical axis h_0 and h_1

$$h_0 = \frac{\ln\frac{\beta}{1-\alpha}}{\ln\frac{p_1}{p_0} - \ln\frac{1-p_1}{1-p_0}} , \tag{28}$$

$$h_1 = \frac{\ln\frac{1-\beta}{\alpha}}{\ln\frac{p_1}{p_0} - \ln\frac{1-p_1}{1-p_0}} . \tag{29}$$

Plotted on the graph after each observation is a point with coordinates m, $K_{(m-1)}+1$ if the Eq. (12) inequality monitored is satisfied, or with coordinates m, $K_{(m-1)}$ if this inequality is not satisfied (here m is the number of observations, $K_{(m-1)}$ is the ordinate of the point corresponding to the m - 1 observation).

Monitoring continues until the point next in the sequence falls outside /136 the boundaries of lines L_1, L_0. If that point is above L_1, the operator is given a "pass," if below L_0, a "fail."

The maximum mathematical expectation of the number of observation required to monitor by the sequential analysis method is

$$E(n)=\frac{-\left(\ln\frac{\beta}{1-\alpha}\right)\left(\ln\frac{1-\beta}{\alpha}\right)}{\left(\ln\frac{p_1}{p_0}\right)\left(\ln\frac{1-p_0}{1+p_1}\right)}. \qquad (30)$$

The following should be pointed out in connection with the use of the sequential analysis method.

Situations wherein the determination of the evaluation can require many more observations than is permitted by the monitoring conditions are possible during the sequential check process, so in those cases when the Eq. (24) and Eq. (25) conditions are not satisfied and the permissible number of observations is exhausted, monitoring can be concluded by increasing the α and β values (reduction in the dependability with which the evaluations are made), or by using a sensored criterion [2].

There are, in addition to the sequential analysis method, other methods requiring for their realization fewer observations than is the case for single sampling.

There is no question of interest in the evaluation method based on the use /137 of Kul'bak's information criterion [8]. The number of observations required when this method is used is found by using the expression

$$n\geqslant\frac{-\left(\ln\frac{\beta}{1-\alpha}\right)\left(\ln\frac{1-\beta}{\alpha}\right)}{\left(\ln\frac{p_1}{p_0}\right)\left(\ln\frac{1-p_0}{1-p_1}\right)}. \qquad (31)$$

Figure 6 shows the gain in the number of observations, 1 - E(n)/n, in terms of the probability of task accomplishment, P, for different monitoring methods as compared with the method based on the information criterion for the case when

$$p_0 = 0,3\ ;\ p_1 = 0,5\ ;\ \alpha = 0,1\ ;\ \beta = 0,2.$$

The mean gain in the number of observations obtained as a result of a sequential check is greatest when $P < P_0$ and $P > P_1$; that is, when an operator with a very low, or a very high, level of training is being monitored.

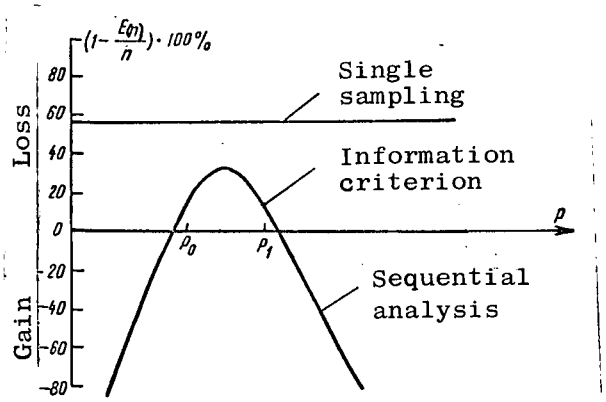


Figure 6. Mean gain in number of observations during monitoring when the information criterion is used.

Use of the information criterion results in a significant gain as compared with the classical method, and even as compared with the sequential analysis method over the section $P_0 < P < P_1$; that is, when operators with average training are being monitored (as will be seen from Figure 6, in this case the number of observations will be reduced approximately 30% as compared with the sequential analysis method).

Thus, if the number of observations is limited by organizational, or by some other possibilities of making them, the monitoring plan can be as follows: /138

Begin Monitoring	End Monitoring
Sequential analysis method.	Sequential analysis method until the number of observations exceeds the value of n from Eq. (31). Monitoring method using the information criterion beginning when the number of observations exceeds the value of n.

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CHAPTER 5 /139

PROCEDURE FOR PROCESSING PSYCHOPHYSIOLOGICAL PARAMETERS

The problem of improving the processing and analysis of psychophysiological information is attracting more and more attention from researchers [1, 2, 3, 4]. Yet there is not, at this time, a description of even the first stage in the deciphering of the material.

The preceding issue of this publication [9] described the polyeffector method of recording psychophysiological parameters (PPP) to make a composite evaluation of man's functional states. The effectiveness of this method is greatly dependent on how well-defined the criteria are for evaluating the indices of the recorded parameters. Parameter is understood to mean the individual recorded reaction (the galvanic skin reaction, electroencephalogram, electrooculogram, for example) that is the component part of the entire set of parameters. Any parameter has a number of indices (latent period, amplitude, reaction duration) reflecting its amplitude frequency and time characteristics.

The effectiveness of the use of each recorded parameter has been cited time and again in the literature. There are special handbooks on the use of phychophysiological parameters. But as has been pointed out, there still is no description of methods for processing psychophysiological information that can fairly be said to be objective and conclusive for evaluating man's sensomotor functions. This is why the researcher is constantly running into a lack of clear cut, stable, requirements and criteria for processing psychophysiological data.

It is necessary to standardize the PPP indices, to generalize and classify methods for analyzing and evaluating changes in the psychophysiological functions. This is a particularly urgent question at this time when attempts are /140 afoot to develop and introduce methods for the automatic processing of psychophysiological data.

Given in what follows is a brief description of the procedure for processing PPP, the required list of indices to be taken into consideration during processing, a formal definition of each, with an indication of the criteria to use in making a quantitative evaluation of the PPP indices. The procedure was

developed in the Functional Condition Evaluation Laboratory of the Division of Ergonomic Research at the VNIITE [All-Union Scientific Research Institute for Aesthetic Styling in Engineering].

The following list of indices, reflecting the dynamics of the recorded parameter, is proposed for purposes of comparability of experimental data obtained under different conditions, as well as for the development of a unified methodological approach to the evaluation of the functional condition of the man-operator:

(1) duration of reaction, t_r (seconds);

(2) latent period of the reaction, t_l (seconds);

(3) duration of anticipatory reaction, t_{an} (seconds);

(4) duration of lag, t_{lag} (seconds);

(5) mean amplitude of the background function, A_m^b (microvolts);

(6) mean amplitude of the reaction to the background, A_{mr}^b (microvolts);

(7) mean amplitude of the reaction when the signal occurs, $A_{m\,r}^s$ (microvolts);

(8) mean amplitude of the reaction in the interval, $A_{m\,r}^i$ (microvolts);

(9) mean frequency of the parameter in the case of a signal, f_m^s, for EEG, EMG (Hz); for EPG, EKG (no/min);

(10) mean frequency of the parameter in the interval, f_m^i, for EEG, EMG (Hz); for EPG, EKG (no/min);

(11) number of conventional units for the integrator in the background (with values of the integrator factor taken into consideration), N_{int}^b;

(12) number of conventional units for the integrator in the case of a signal, N_{int}^s;

(13) number of conventional units for the integrator in the interval, N_{int}^i.

A brief description of the parameters, and the procedure to use in processing them, follows.

1. Electroencephalogram (EEG)

The changes in the background of the EEG (sections of the tracing prior to the introduction of the first signal) when the signal occurs, in the intervals (the time between the termination of the preceding, and the initiation

of the subsequent, signal), and after the work is completed, are informative in processing the electroencephalogram. If signal presentation is discrete, it is feasible to separate the background and the intervals into sections equal /141
to the time of signal duration when measuring the indices.

Duration of reaction, t_r

Taken for the reaction is that desynchronization (depression) of the rhythm for which the amplitude is 1/3d, or less, of the mean background amplitude, and the duration of such reduction is at least 1 second (Figure 1) [6]. The background amplitude is determined by averaging the maximum values for the amplitudes of the separate sections of the background trace comprising no more than 5 seconds. If the desynchronization caused by the signal interrupts the rhythm with a brief flash (less than 1 second), the latter can be included in the duration of the reaction.

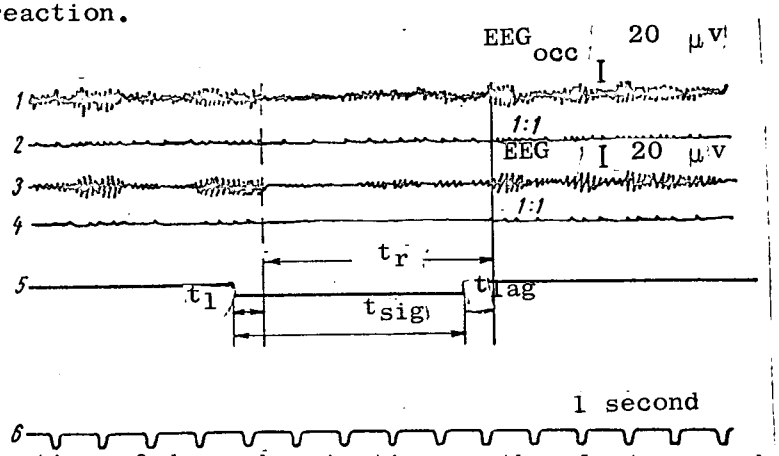

Figure 1. Sample reaction of desynchronization on the electroencephalogram --1 - EEG of occipital region of the brain; 2 - integrator pulses; 3 - alpha-rhythm; 4 - integrator pulses; 5 - signal marker; 6 - time marker.

Latent period of the reaction, t_1

The latent period of the reaction is considered to be the time from the beginning of the presentation of the signal to the time of appearance of the reaction (Figure 1). It is desirable to use a segment of the trace for the time marker to measure the latent period of the reactions, as well as other time characteristics.

The minimum latent period of depression of the alpha-rhythm is between /142
0.1 and 0.2 second, on the average. The magnitude of the latent period can

change significantly in the same person during the test. Ordinarily, the more intensive the stimulation, the smaller the magnitude of the latent period, and the greater the expression of the depression.

Duration of anticipatory reaction, t_{an}

It is important that reactions between signals, timed to the signal and called anticipatory reactions [8], be taken into consideration in analyzing sensomotor activity, including the process of signal anticipation. The significance of these reactions is in the unique reflector training of the analyzer systems to perceive the anticipated signal.

The effect of anticipation appears in reactions that lead the signal and are translated into reaction to the signal. Anticipatory reaction time is measured from the beginning of this reaction to the time the signal is cut (Figure 2). It should be noted that when there is an anticipatory reaction that is translated into reaction to the signal, there is no latent period during this latter process

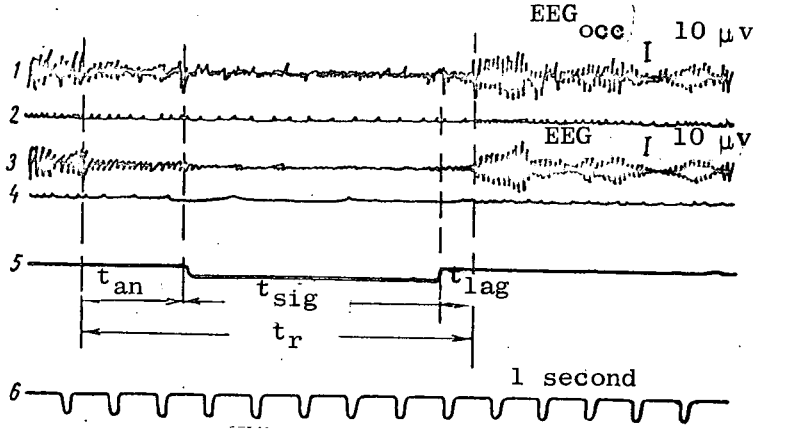

Figure 2. Sample anticipatory reaction on the EEG --1 - EEG of occipital region of the brain; 2 - integrator pulses; 3 - alpha-rhythm; 4 - integrator pulses; 5 - signal marker; 6 - time marker.

Duration of lag, t_{lag}

Lag is considered to be an extension of the reaction after the signal has been cut out (Figure 3), and t_{lag} is the duration of this extension.

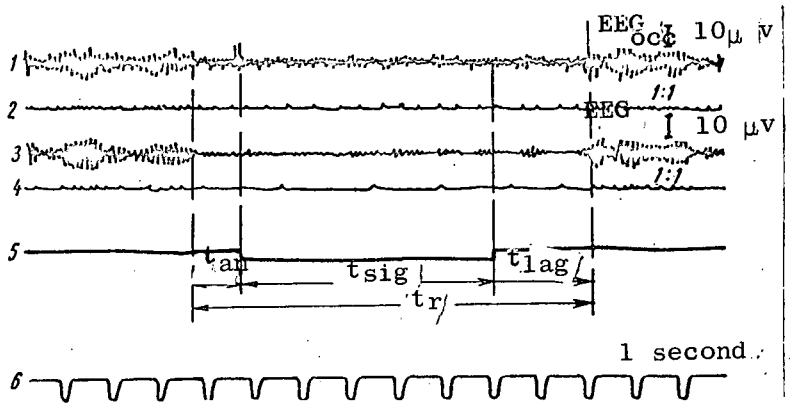

Figure 3. Sample lag reaction on the electroencephalogram. --1 - EEG of occipital region of the brain; 2 - integrator pulses; 3 - alpha-rhythm; 4 - integrator pulses; 5 - signal marker; 6 - time marker.

Number of reactions when signal is present, N_j

The following notation usually is used for the statistical processing of the data [5, 6]:

i - presence of signal;

i_0 - no signal;

j - presence of reaction;

j_0 - no reaction;

N_j - number of reactions in the experiment being analyzed;

N_i - total number of signals in the experiment being analyzed.

Several reactions can be recorded when the conditions are such that the signal functions for a long period of time. And the larger N_j, the greater the effect of the signal. The number of desynchronizations during the period the signal is functioning is calculated during the processing.

Number of "false alarms," N_j (for i_0)

The "false alarm" not directly associated with the signal, and which occurs when there is no signal, is included among the reactions between signals. "False alarms" are taken into consideration in the background, and in the intervals.

Amplitude of the electroencephalogram, A

The measurement of the amplitude can be only an approximation when manual processing methods are used. The magnitude of the amplitude on the working sections is calculated in the same way that one calculated the background amplitude, that is, by averaging the maximum values for the amplitude for individual /144 sections of the trace that are no longer than 5 seconds. The probability analysis method [9] can be used in addition to the method indicated to process EEG.

The general level of cortical activity can be defined as:

the ratio of the mean frequency of oscillation in the EEG to its mean amplitude (for example, if it is necessary to determine the level of activity of the EEG to the signal, the latter can be expressed as $U_s = f_m^s/A_m^s$, Hz/ μv);

by calculating the conventional integrator units, which provides a quantitative evaluation of the total bioelectrical activity.

2. Electrooculogram (EOG)

The processing of the EOG begins with separation of working sections and background on the trace (Figure 4). When signals are discrete the intervals between them too can be separated. The working sections are understood to mean the periods during which the signal is functioning and the intervals between signals. The number of eye movements (steps), and the duration of fixation (Figure 4), are found for each separate section.

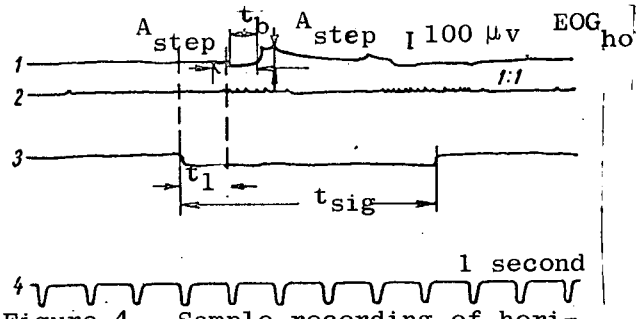

Figure 4. Sample recording of horizontal eye movements. --1 - EOG of horizontal movements; 2 - integrator pulses; 3 - signal marker; 4 - time marker.

It is desirable to take eye movements providing pulses of at least 30 μv [7] in order to compare the results by steps. Thus, analysis of the EOG means considering step amplitudes of 30 μv, and more. This can be explained by the following peculiarities in the behavior of the oculomotor apparatus. Different amplifier response is required to record /145 the EOG because what is expressed on the EOG differs with different subjects. This makes it difficult to compare EOGs for different subjects because some-

times reactions that are equal in terms of physiological force (amplitude) can be expressed differently simply because of amplification. The extreme expression of this incompatibility of results, and loss of data, is lack of reaction on the trace because of low amplification.

It is desirable to run control tests at the beginning of the experiment when doing electrooculography in order to provide for methodological validity of the experiment, particularly when the objective of the investigation is to establish the dependency of oculomotor activity on the degree to which the information field is loaded. The purpose of these tests is to determine the magnitude of the amplitude of movement when the eyes move to different sections of the information field, with their angular magnitudes taken into consideration. The data obtained on the relationship between the sizes of the objects studied and the magnitudes of the amplitude of eyeball movement provide the means for judging the strategy of eye behavior under concrete conditions, within known limits.

Fixation is understood to mean the retention of the eyeball in a definite position, and is expressed by a segment of the trace between two adjacent steps. Out data tell us that the minimum duration of fixation is 0.2 second, on the average, and that the maximum fixation time can differ with the task given the subject.

The number of conventional integrator units expressing the total activeness of eye movements over a selected time segment is calculated when integrator data are available, and this is in addition to the calculation of the indices indicated.

The latent eye movement period must be measured to determine the moment of appearance of oculomotor activity (particularly in tachistoscopic investigations).

3. Galvanic Skin Reaction (GSR)

Duration of reaction, t_r

The duration of the GSR is found by measuring the distance from the time of deflection of the curve from the isoline to its return to it. If the pur-

pose of the experiment is to evaluate the functional condition, associated with stress activity, it is desirable to take into consideration the expressiveness /146 of the GSR, which can be evaluated by the magnitude of the deflection from the isoline every 30 seconds.

The number of spontaneous oscillations in 60 seconds can be determined to evaluate the original functional condition. The background is considered as "quiet," when there are no more than 2 or 3 spontaneous oscillations per 100 seconds of trace.

Latent period of the reaction, t_1

The beginning of the reaction is considered to be the deflection of the background line from the horizontal, up or down, corresponding to the negative, or positive, phase (Figure 5). If the reaction begins within 1 second after initiation of the signal, it can be taken that reaction to the particular signal has occurred. If the latent period is less than 1 second, the reaction can be considered to be the effect of a nonspecific origin,[12] or as a result of anticipation.

The GSR can be single-, two-, and multiphase (Fig.6).

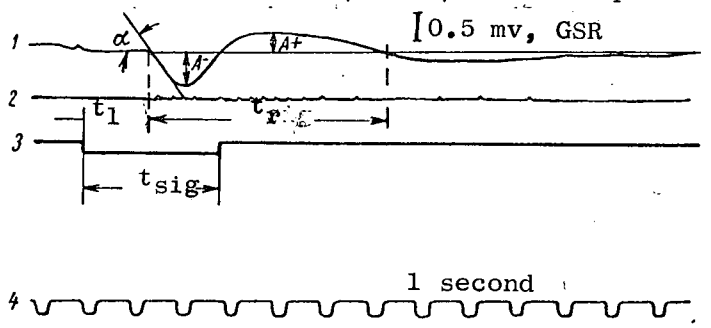

Figure 5. An example of two-phase galvanic skin reaction. --1 - GSR; 2 - integrator pulses; 3 - signal marker; 4 - time marker.

GSR amplitude

The amplitude of the GSR is one of the significant indices of the strength of the reaction, along with such indices as the multiphasality.

The evaluation of the single-phase reaction amplitude includes measuring the maximum deflection of the curve from the isoline in microvolts, but in the case of the multiphase evaluation the mean amplitude of the reaction, in microvolts, is calculated with maximum deflections taken into consideration. The criterion of comparability of results for different subjects that we have adopted is a deflection of the pen of 100 microvolts, and this agrees with the data in the literature [7]. Deflections of less than 100 microvolts during a reaction are not used. The deflection from the isoline corresponding to 100 microvolts is determined during

[12] The peculiarity of the galvanic skin reaction is that it does not stem from a specific stimulus. It can be caused by any action: external (light, sound, tactile stimuli, and others); internal (change in the condition of the internal organs); proprioreceptive. GSR also is accompanied by intensive mental activity. Each of the actions listed as causing GSR is accompanied by increased stress, by increased activity on the part of the organism.

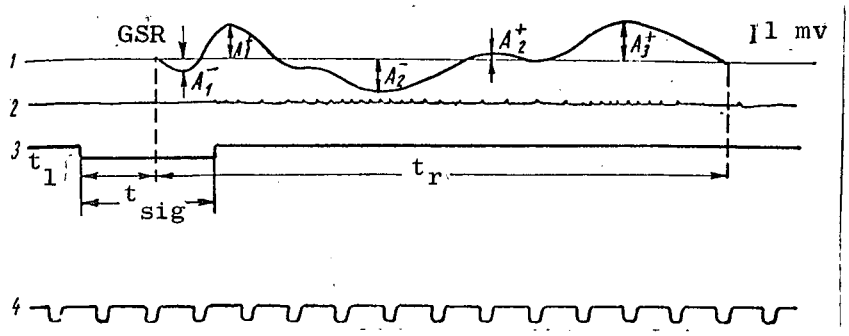

Figure 6. Sample of multiphase galvanic skin reaction. --1 - GSR; 2 - integrator pulses; 3 - signal marker; 4 - time marker.

the calibration made at the outset of the experiment for purposes of convenience in evaluating GSR data. The deflection of the pen from the isoline during the calibration for 500 microvolts should be 5 mm, for example. A deflection of the pen from the isoline of 1 mm, and more, is taken during the reaction.

But in those cases when the objects of study are individual subject traits that turn up during the conduct of the GSR in particular this reaction evaluation method is not adequate. It is necessary to consider any deflections of the pen from the isoline. It is desirable to measure any deflection over a section of 30 seconds in order to avoid a mistaken GSR evaluation associated with wandering of the pen, particularly when slight deflections from the isoline extending over a long time segment are noted. If the deflection is the same at all points it is obvious that the cause is wandering of the pen.

Taken into consideration in some cases, in addition to the indices noted /148 and characterizing the strength of the GSR, is the rate of its increase. The rate of increase in the reaction is understood to mean the time from the instant of deflection of the pen from the isoline to the reaching of maximum deflection.

4. Pulsimetry

Change in pulse rate integrally reflects the different aspects of psychophysiological stress; muscular, thermoregulation, nervous-emotional, and others. Hence, pulse rate when performing some particular activity can be used to evaluate the degree of complexity of the operation being performed.

An increase in the pulse rate can be noted when doing muscular work, when there is emotional excitement, and, to a lesser degree, during strenuous mental

work. The pulse rate can go to 150 to 180 beats per minute at times of pronounced stress.

The frequency, and the period, of the cardiac cycle (primarily the distance between the high-amplitude spikes) of all the information on the recordings, are taken into consideration most often in experiments designed to evaluate functional conditions by using pulsimetry.

Variations in the pulse on the recording are expressed in the form of individual spikes, so when the recording is processed the number of spikes over a measured time segment is counted (and converted for one minute). For example, if there are 24 spikes in a 20 second segment (on the time marker) the mean pulse rate in this case is 72 per minute.

The coefficient of variability, CV, in the period of the cardiac cycles is determined in addition to the mean heartbeat rate. The following formula is used

$$CV = \frac{\sigma}{m} \cdot 100\% ,$$

where

m is the mean length of the cardiac cycle over the segment of the recording measured;

$$\sigma = \sqrt{\sum_{i=1}^{n} (l_i - m)^2} ;$$

n is the number of cycles over the segment;

l is the length of each individual cycle.

5. Electropneumogram (EPG) /149

The following characteristics of the EPG contain information for use in evaluating functional conditions: respiration rate, amplitude of respiration waves, ratio of inhalation and exhalation depths. What usually is observed under stress is a quickening of breathing accompanied by a reduction in depth, and disturbances in the shape of the respiration curve.

The mean respiration rate is determined in a manner similar to that used to determine the mean pulse rate, by counting the number of breathing movements per minute.

The shape of the respiration curve can be expressed by the ratio

$$\left|\frac{\varphi}{\varepsilon}\right| = \frac{\text{length of inhalation}}{\text{length of exhalation}},$$

The correspondence between the inhalation and exhalation phases of the EPG, that is, the phases of inhalation and exhalation, should be marked precisely and should be established in order to determine this ratio.

The depth (amplitude) ratio is determined as the difference in the magnitudes of the inhalation and exhalation amplitudes over the specific section of the recording.

The mean amplitude of the respiratory waves usually is measured over no more than a 10 second section of the recording.

6. Electromyogram (EMG)

The EMG reaction, as a responsive motor reaction (under conditions of cyclic anticipation of signals) is, along with the vocal response, an additional index characterizing man's psychophysiological activity. The EMG recording should distinguish between the reaction to a signal and the reaction taking place during the periods between signals.

The subject must be made to relax his muscles completely before the experiment, something that can be reflected on the recording by a straight isoline, or by small oscillations (5 to 15 microvolts), if a quality recording is to be obtained, one reflecting the true state of muscular strain, without the introduction of artefacts.

If the isoline in the background indicates lack of muscular strain, any change in oscillations in the experiment can be considered a reaction.

EMG reactions therefore must take into consideration the status of electrical activity causing a change in the amplitude of the oscillations on the recording. If signals are represented as cyclical, the appearance of the EMG reactions, as has been pointed out, can take place at different periods of signal functioning (at the beginning, in the middle, at the end), at the boundary of signal functioning, and the succeeding interval, in the interval following the signal. /150

It is desirable to record a tensiogram of the motor reaction (Figure 7) simultaneously with the EMG in order to provide a clear-cut separation of the time of appearance of the motor reaction and its latent period.

The duration of the tensiogram (in the case of short motor responses) can be taken conventionally as the duration of the motor reaction proper.

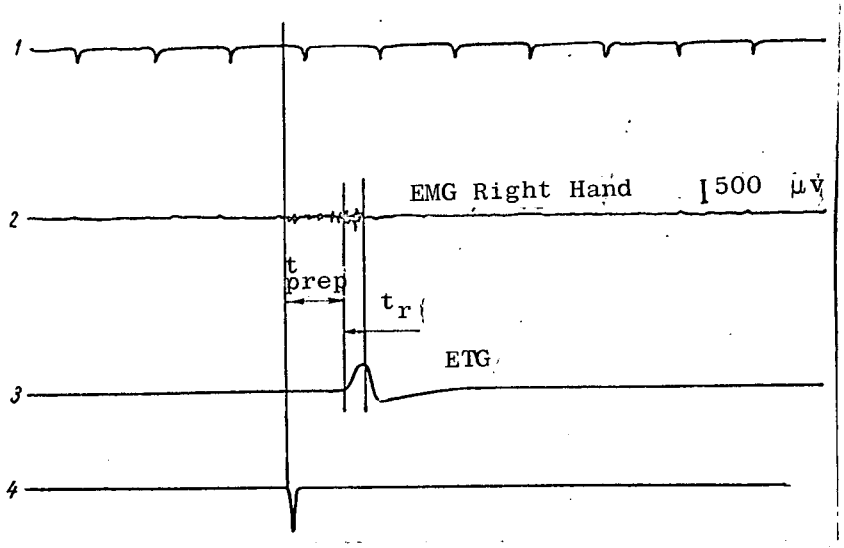

Figure 7. Sample of simultaneous recording of an electromyogram and electrotensiogram (note the low muscle voltage prior to movement) --1 - time marker; 2 - electromyogram of the right hand flexor carpi; 3 - electrotensiogram; 4 - signal marker.

Duration of motor reaction, t_r

A brief increase in the amplitude of the EMG during the time the signal is in effect must be considered a motor reaction. Duration of the reaction is taken to be the period from the beginning of the increase in muscular strain to the return of the amplitude of the contractions to the original level (Figure 8). /151

Latent period of motor reaction, t_l

The latent period of the EMG can be corrected by the tensiogram. The magnitude of the latent period of the motor reaction can differ with experiment conditions (magnitudes of intervals between signals, degree of complexity of signal, how strong its influence is), with the individual-typological peculiarities of the subject, and his degree of training, and others.

The minimum latent period of motor reaction is between 150 and 225 milliseconds, according to the literature on the subject. The latent period of the responsive motor reaction to the particular signal increases with increase in signal complexity.

Research shows that in the case of suprathreshold intensity of the stimulus the time of simple motor reaction is determined primarily by the physical nature of the stimulus, and by the peculiarities of the sensing receptor. The shortest simple reaction time, 105 to 180 milliseconds, is noted when audible and touch signals are used. This can be explained by the fact that the time required for the stimulus to penetrate the audible receptors and the skin's /152 mechanoreceptors is very short. The reaction time for a visual signal is longer, 150 to 225 milliseconds, because a photochemical process takes place between the onset of the action by the stimulus and the initiation of the corresponding nerve impulse.

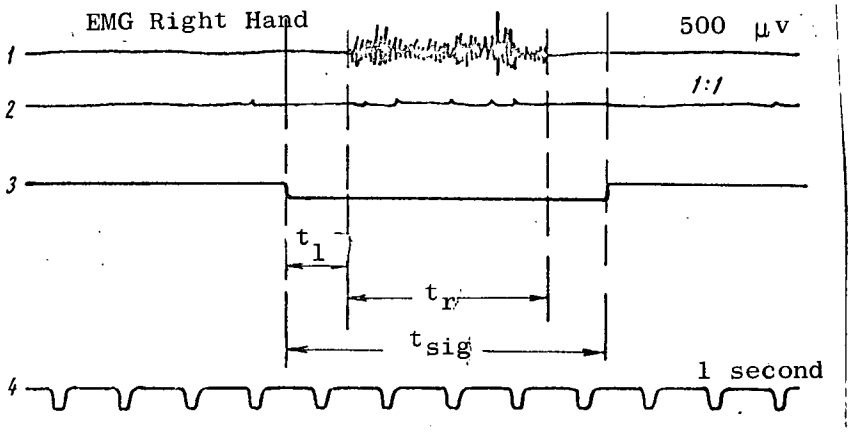

Figure 8. Sample of duration of motor reaction to a signal. --1 - electromyogram of right hand flexor carpi; 2 - integrator pulses; 3 - signal marker; 4 - time marker.

Anticipatory reaction time

Any sensomotor activity, particularly if carried out under cyclic anticipation of signal conditions, usually includes an element of expectation that appears in the form of a different degree of increase in muscle strain.

This effect is very marked when amplification is high. It should be noted that if this effect precedes the signal in time it can be reevaluated as an anticipatory reaction.

The EMG reaction can be considered an anticipatory reaction with a high degree of probability when it appears during amplification when the motor reaction proper is being recorded.

The after effect of the motor reaction can be observed if there is any difficulty in recognizing the signal, particularly when it is necessary to separate the signal from the noise when weak stimuli conditions prevail.

The reaction aftereffect is the period the reaction continues after the signal has been cut out. The time of the aftereffect is measured from the time the signal is cut out to complete disappearance of the reaction (Figure 9).

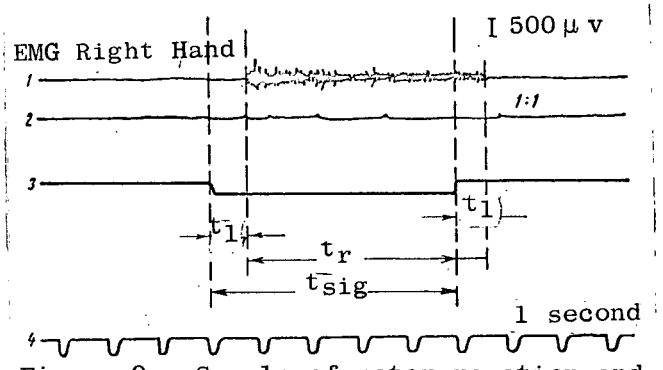

Figure 9. Sample of motor reaction and aftereffect. --1 - electromyogram of right hand flexor carpi; 2 - integrator pulses; 3 - signal marker; 4 - time marker.

Amplitude of motor reaction

Three or four values of potential oscillation, greatest, least, mean (in mm), are measured to determine the EMG amplitude. The mean value of the amplitude is then calculated and converted into microvolts.

Number of motor reactions to a signal

A subject will be uncertain of his recognition accuracy, and can react to the signal more than once, when the conditions under which the experiment are conducted become complicated by recognition difficulties. When this happens the number of reactions, N_j, for the period of time the signal is working can be counted (Figure 10). Difficult conditions can result in strain on the muscles and on the non-working hand (Figure 11).

Number of motor reactions between signals /154

EMG reactions between signals appear most frequently when conditions are such that the signal differences are complicated. A distinction must be made between reactions that occur between signals and those that result from anticipation. The former can appear at any time during the interval, but the

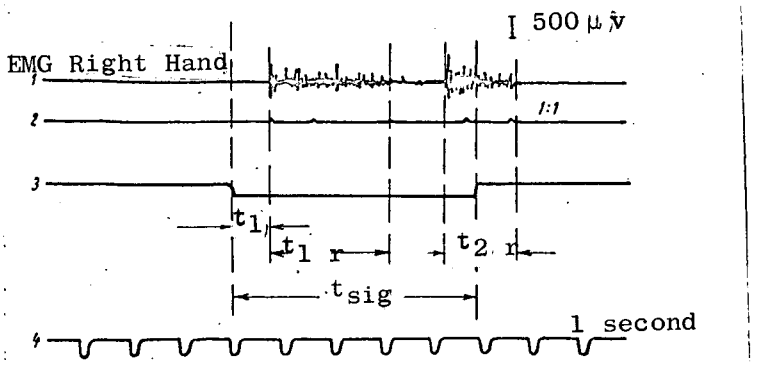

Figure 10. Sample of two motor reactions to a signal. --1 - electromyogram of right hand flexor carpi; 2 - integrator pulses; 3 - signal marker; 4 - time marker.

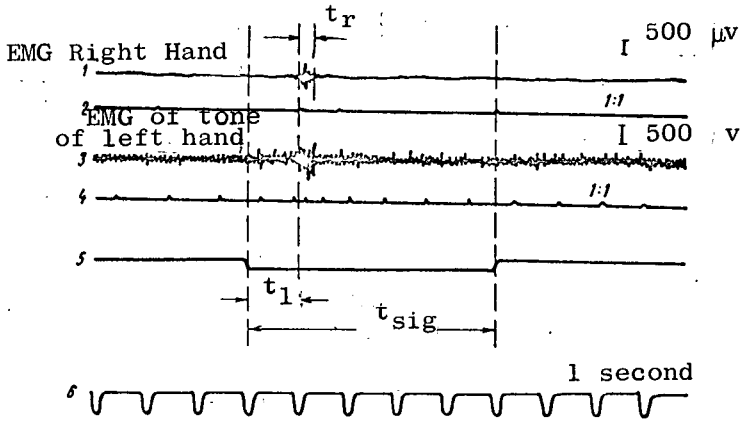

Figure 11. Sample of short motor reaction of working muscle and of strain on non-working muscle. --1 - electromyogram of right hand flexor carpi; 2 - integrator pulses; 3 - electromyogram of left hand flexor carpi; 4 - integrator pulses; 5 - signal marker; 6 - time marker.

latter are timed to the signal. The number of reactions between signals is found by counting all the reactions occurring in the interval, excluding anticipatory reactions.

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CHAPTER 6

/155

PSYCHOLOGICAL STRESS OF SPACE FLIGHT

The concept of "psychological stress" is becoming increasingly important, particularly in connection with mastering space. This chapter will discuss stress related to the human psyche being prepared for flight, or already in flight. First of all, it must be understood that psychological stress is a functional condition that is not so much the result of actual space flight, as, perhaps, the anticipation of it.

Any test imposed upon man (at work, or in sports, for example) begins at the moment he becomes aware of the fact that he must take the test. Psychological stress of space flight primarily is the anticipation, or the anticipated possibility, that it will be undertaken. It is precisely this approach that should be used to determine the entire complex of investigations that accompany preparations for flight and directed at exposing the stressors, the factors causing stress.

The first investigations in this field revealed that stressors entering the picture as relatively elementary actions, or as total situations, can be broken down by referring to the job description, primarily that of pilot action, as well as on the basis of data obtained during space flights. Intuitive assumptions are a close second in exposing the suspected factors in stressor action.

It is interesting to note that during the preparations for the first space flights factors not yet observed were included among the psychological stressors./156 The assumption of an inevitable disturbance in coordination of movements in the weightless state, for example, proved to be more than a little exaggerated. Actually, what was found was that there were no disturbances in locomotion, in delicate motor skills, that all imperfections of movements of this type were associated with the ordinary behavior of the subjects. Then it was discovered that phenomena associated with the activity of the postural motor complexes were stressors. False perceptions of spatial position (illusions), causing the sensation of forced pull, and a feeling of impending loss of orientation, proved to be extremely strong stressors [4].

Theoretical and practical experience in the field of aviation medicine and doctor-pilot expertise was reviewed and summarized in a series of investigations. The result was to advance the principle of reproduction, and a flight job description, as applicable to space flight, was drafted. The proposition that a diagnosis of "healthy" with respect to a pilot still did not provide the basis for the automatic conclusion that he was fit to do a pilot's job played a special role. This is precisely the reason for the development of the standard stresses used in tests to evaluate the functional capabilities of a man from the somatic and psychological aspects.

During the early stages of training for flights, when questions of health were the center of attention, the psychological aspect of the effect of a particular standard stress was not isolated specifically. The task of devising a job description, with the psychological aspect in mind, required the development of a new approach from the position of the principle of reproduction [2].

The following possible stressors were distinguished in the job description.

1. Continuity of the action. It has been shown that even when automatic controls are installed, all of the more vital periods of the flight require constant action.

2. Mandatory, or compulsory, sequence in which the flight is made. Involved here is the mandatory sequence of actions in accordance with a preplanned program, or evolving during the flight. It is impossible to change the sequence in which the work operations are performed.

3. Lack of, or limit on, time. Their independent values in flying have been confirmed by experimental data. Lack of, or limit on, time was considered the limiter, not only on the time to complete the actions and make the decisions, but also on perception of communications and signals. /157

4. The factor of "extendability" of functions. It was established as a result of man's inability in flight to see directly the result of his action. The useful result of the work can be perceived indirectly by instrument readings. The talk-listen function, for example, is "extended" by radio transmitters and receivers, the seeing function by optics and television, and the kinesthetic function by control organs. Indicators and meters are built into the functional circuit between the effector (output) and affector (input) links.

5. The postural factor, in the broad sense; that is, combining such actions as change in pressure on the area of support, change in the position of the area of support, lack of an area of support (during weightlessness), loss of the area of support (similar to the effect noted when the spacecraft makes certain maneuvers, and arbitrary loss, as during parachute jumping). Associated with them is the onset of psychological stress during sensations of falling, sinking, during illusions, as well as difficulties in training the pilot, particularly as a result of the formation of such schemes (in terms of type of body scheme) as "man - spacecraft," "man - spacecraft - surrounding space," "man - nonsupporting space" ("space walking").

6. The novelty factor, appearing during the waiting period, as well as during activity. Stressors "due to novelty" depend on individual psychological peculiarities determining the method and style of future playback, and can include phantoms, in the strict sense of the word.

7. The factor of changed (reduced) afferentation. A deficit in afferentation as a result of sensory isolation, sensory deprivation, and others, was assumed.

The job description based on the principle of reproduction made it possible to isolate the psychological actions that could lead to stress in the form of definite psychological syndromes. The experimental investigations of these actions had two purposes:

from the syndrome, as occurring, arrive at a judgment as to the type of model of the standard in terms of the real life situation (diagnostics for the situation in terms of the syndrome);

from reproduction of the situation in the model, establish the new /158 forms of stress, and identify them from those known in real life (diagnostics for the syndrome in terms of situation).

Distinguished in these experiments were forms of psychological stress when time was lacking in those types of activity characterized by continuity and a mandatory sequence of change in the working operations. Studied as well were paroxysmal onsets of psychological stress occurring upon perception of useful signals in the background of stimuli-noises, close to the useful signal. Criteria for man's high and reduced resistances to interference were established,

as was the correspondence between the forms of psychological stress in different situations in space, and the stressor effects of altitude and depth of closed and open, unoriented space.

Analysis of the experimental data on psychological stress was made on the basis of clinical observations of nervous and mental diseases. Comparison between the different psychological syndromes as the consequences of stressor factors of space flight and the syndromes of nervous and mental disturbances also were of definite value.

1. Principal Psychological Stressors. Hypodynamia.

Hypodynamia can be considered a psychological stressor. Expressed within the definition of hypodynamia is the concept of suppression, or of insufficiency; in other words, of a discrepancy between the need during motor activity, and the conditions that interfere with that need. Hypodynamia under space flight conditions, in so far as its depth mechanisms are concerned, acts on the psyche, not only as a result of the discrepancy between the "claim" level and the "achievement" level, but also as a result of the mismatch between afferent (sensibility) links intact and under "load," and the effector (motor) links of a unified functional chain of motor acts, which too are intact, but under a limited "load." Annoying mental states can be associated with this mismatch, and can be expressed in neurotic manifestations, or in gnostic phenomena. Hypodynamia contributes to the development of neurotic reactions among some people during a group experiment.

Hypodynamia under transitional conditions (from weightlessness to ordinary conditions, for example) affects vascular regulation, primarily the venous tone, and leading to the occurrence of vascular-dystonic syncopal readiness. Syncopal readiness itself is a stressor because it gives rise to the feeling of /159 faintness, inertia, fear in the face of having to take an active part in things and to overcome the difficulties that must be faced. Psychological stress of this type, that is, arising as a result of physiological discomfort and based on a sufficiently strong emotional experience associated with a fluctuating level of mental and motor activity, is very comparable to stress occurring during "diseases of movement" attributable to the cumulative effect of motion sickness.

An upset in the calcium metabolism during hypodynamia is not, at this time, directly associated with psychological stress. There is no significant change in the thresholds of acoustical perception in the range of frequencies equated to bone conduction.

Group hypodynamia on long flights still will be the subject of careful investigations [2, 5].

Limitation on the Volume of Small Spaces

Discussions of small volume spaces in connection with space flights usually involve the conventionally closed and self-contained pressurized capsules moving about in space.

The following factors become possible stressors under these conditions.

1. Limitedness. Intended here is a space known under ordinary conditions as cramped. This is hardly a vital factor as a stressor in the case of one man, but it can appear if the man who finds himself in a cramped space begins to feel a closeness of the type described as the "walls (ceiling) closing in." It is known that limitation on the volume of a space can give rise to a sense of being covered up and comfortable. Peter I, for example, preferred to rest in tiny rooms with barely enough space to accomodate him. The confinement becomes a definite stressor if several men are in a small space. What one is discussing in this case is congestion. This question can be reviewed by group psychology as applicable to space flight.

2. Closure. Closure is a significant psychological stressor upon the occurrence of the emotional experience of being walled in, of fear of suffocating, of shouts not being heard by those around. In addition to these obsessive fears, there is the recognition of the impossibility of rapid departure in case of danger in the case of real pressurized capsules.

3. Isolation. Man in the capsule of a spacecraft, or in a bathyscaphe, /160 is isolated from the surrounding world not so much by the shells of the capsule as by the presence (and the movement about) of the capsule in a space that contains no atmosphere. The most important aspect of isolation of this type is the solution to the problem of the conditions for communicating with the outside world (difficulty in establishing communications, interference on the

communication channels and short periods of communication, terseness of the language used for communication, and the like).

These factors create a complex stressor, the result of a combination of concepts associated with the experience of alienation (the "isolation syndrome").

An ecological closure, a self-contained system of water supply, food, lighting, and the like, was created for the experiments with long single and group isolation. The design of the soundproof chamber was such that the penetration of sound, light, and vibration signals was precluded. A number of unique psychological phenomena were isolated in the course of investigating the condition of the subjects [1, 2]. Criteria were found for determining the readiness of a man to stay in isolation and to engage in purposeful activity, and such unusual mental states as a tendency toward the hypnoid phase, eudetic concepts, and neurotic reactions to absence of feedback, were described. Psychological stress was not sharply expressed in these experiments, but was distinguished by great phenomenological diversity attributable to the individual psychological differences in the subjects.

Limitation of Sensory Information

Sensory information combines the concepts of afferentation and signal information. Associated with the concept of signal information are questions concerned with reception, transmission, and information processing as equated to man's activities. Afferentation is a psychophysiological concept.

Limitation of signal information primarily is a limitation associated with communications. The terseness of the language used for communication depends on the technical qualities of the communication equipment, and on the different aspects of situations. The stressor action of this factor can be associated with messages with inadequate information content, as well as with garbled messages. The typical forms of the onset of stress are reactions of the neurotic type.

A limitation on signal information can be observed in the case of faulty /161
instruments, lag in indications, and false readings. It is difficult to refer to the latter simply as a limitation because we are talking about false information. The stressor action of this factor has been studied for certain in-flight

situations. There sometimes is a false mental reaction to the instrument as well as to its uncontrollable "nature," "its" behavior. The stress that develops in this case has the features of the relationship syndrome.

Limitation of signal information refers to direct perception, primarily visual, when the surroundings do not provide a sufficient number of landmarks for reckoning position in space (for purposes of navigation) or for evaluating the condition of the earth's surface, or that of another planet. It is premature to discuss this in terms of its being a stressor, but there is no doubt about the fact that it does cause a stressor situation. There is a great deal that should be reviewed at this point from the point of view of the influence of novelty (of the uncertainty) [2, 5, 7].

The limitedness of sensory signaling as afferentation has a long history in pathology and in psychophysiology (the inclusion of the sense organs in the experiments, observation of those suffering from defective sense organs and injury to the surface and deep sensitivity). The version that afferent impulses in the sphere of movements in the weightless state were limited was persistent during the first of the space investigations. It even was suggested that proprioception is disconnected. Today this latter can be deemed an exaggeration. But in the work done along this line, the first questions dealing with limitation of incoming information and afferentation were studied jointly with the processes characterizing an excess of information and afferentation [5].

The excess in signal information comes about because queries and conversations by other subscribers can be carried by the channels. This raises the problem of perceiving useful signals against the background of noise close to the useful signal. There are other cases when this excess of information is not so sharply defined. This can come about during queries and correcting commands sent from the control station and is by way of being a second activity, duplicating in concept what the person already has done. This is the sort of thing that sometimes takes place among pilots flying in formation when the aircraft next ahead originates a double signaling that duplicates the navigational data of own aircraft. These are the typical stress situations of confusing prompting, first described by S. N. Davidenkov for shy lecturers who therefore read the

written text of the lecture. In cases such as these the stress appears as /162
sudden loss of thought, flushing, and sometimes in fainting [3].

An excess in the flow of information acts as a stressor when the person attempts to perceive the flow completely. The clearest example is the distressing experience of those who are born blind, but who regain their sight as a result of surgery. The information coming to them within the framework of visual afferentation, naturally, is not picked up by the unpracticed eye and everything "flows through the fingers." Also known are distressing situations arising in the dark among neurotic subjects and among children. This often is a lack of the visual afferentation necessary for mental tone.

The same is true in the field of hearing. Dead silence, anticipated as a possible stressor in anticipation of space flight, is not a factor because of the operation of the equipment aboard the spacecraft, and the noise generated by man. Silence, as such, should be considered as a stressor in some situations, however. An example would be when one's own shout seems strange. A special form of stress occurs during voice changes that occur in man in an oxygen-helium environment. Here one's speech resembles the voice given Pinocchio, providing a unique experience with inflections of something incomprehensible, obscene.

Monotony

Monotony, as an independent phenomenon, is of great interest, first because there are a great many types of jobs that are monotonous, and second, because monotony, the personification of sameness, causes the whole gamut of psychic conditions, beginning with the ordinary sensation of boredom, and irresistible drowsiness (which is sufficient for the appearance of stunning mistakes and oversights, causing stress), and ending with the most severe manifestations of disturbance.

Comparatively simple actions, flickers, repeated low sounds, can cause different mental states. The calming effect of rain falling on a roof, or the clicking of train wheels, is known. But the sounds of water dripping from a leaky faucet quickly becomes a disturbance. Characteristic in this regard is seasickness, or "motion sickness" caused by the motion of a ship, buffeting of /163
an aircraft, and the rotary motion of a spacecraft. The onset of stress when

it is necessary to act (when suffering from "motion sickness") probably is the result of a mechanism referred to in connection with readiness to faint [3].

The spontaneous course of "motion sickness" seems to be an incongruous action. A monotonous, "cheerless," action results in a condition that occurs cyclically, or step-like. The question of tuning out monotonous actions has been looked into from the point of view of comparing the resonant frequencies of the organism and the frequencies characteristic of the acting factor, particularly by the use of electrographic means. The future direction of this work is leading into the field of physiology and pathology as a result of stimulation by becoming accustomed to electrodes. Here, at the crossing of the effect of the factors of frequency of stimulus and localization of the electrode in the brain, is where it is possible to see the stress at the moment of "birth."

Monotony of the environment has come to be spoken of again in broader, albeit less definite, terms in connection with the problem of isolation. Monotony of the environment was discussed in aviation and space medicine after observations made during World War II. Pilots flying long night missions became apathetic, their attention was blunted, despite the danger and the responsibility. V. Kherson began to talk glibly about "psychological boredom." American scientists, later on, were to introduce the term "cut off from the earth." The history of Soviet physiology provides a ready entry to the problem of isolation. I. P. Pavlov's idea of "towers of silence" was close to all Soviet specialists in aviation and space medicine.

The concepts of sensory cold, sensory deprivation, speaking figuratively of the fact that the human sense organs, always active, and under "bombing" signals from the outside world, remain underloaded, have arisen in discussions of the effect of weightlessness, of isolation. Man loses the activity of consciousness peculiar to him, and which is "fed" or infected, from without. This postulation has found reinforcement in learning about reticular formation, about the limbic brain, and others. Taking this approach to the problem of isolation (in connection with the monotony of the environment), one can discuss what it is that man in isolation is lacking, without the special aspect of what it is that is acting on him. Then it becomes convenient to break down into two categories all experiments dealing with the problem of isolation. The first /164

has for its object the establishment of the most rigid restrictions (isolation) between man and the environment. These include, in particular, the experiments with man staying in immersion equipment in special clothing with the appropriate life support systems. The experiments included in the second category do not have these rigid restrictions.

The experiments that submerged and kept man "waterborne" established a significant blockade against the outside world (claustrum). The subjects, during the time they were "waterborne" could not learn to acquire information from without, of course. The capacity of the remaining channels was too small. Attempts to establish communications with the outside world without using radiotelephone communications would have required extraordinary effort. The restrictions on mobility when submerged, and the feeling of the special clothing, however paradoxical it may seem, leads to a sense of being swaddled and of safety of existence. Thus, it is that the ideal, if not a "tower," then a "chrysalis," of silence has been created. Monotony becomes a stressor here. Experiments have shown that stay in these conditions is distressing for man, who loses his capacity for purposeful and productive thought, whose attention is concentrated on tactile impressions [3, 5].

2. Problems Associated with Long Periods of Activity by Autonomous Groups

Group psychology, as an independent field of research, developed significantly in connection with the tasks of group space flight.

The original premise of group psychology held that the stability and effectiveness of the interrelated and interdependent activity of the members of the group were determined by the individual contribution made by each of those participating in the group, as well as by the nature, and degree, of their interaction.

Two problems arose in group psychology:

the problem of interrelated and interdependent activity;

the problem of association within the group.

The second of these has been around a long time. Analysis of the experiences of those who winter over, of those who have participated in long expeditions, and of others is of interest as applicable to space flight. The first

problem has been discussed in documents on sports, and, in part, in documents /165
on the experience of flight operations.

The research program had two basic stages, the laboratory experiment modeling the interrelated activity of two, three, and more, operators, and investigations under "full scale" conditions (group isolation under laboratory conditions, Antarctic, and other expeditions).

Possible stressor effects in different situations, characterized by difficulties in forming up the group, its training, and its work as a unified functional entity, were reviewed.

The experimental direction taken (modeling of the activity) was based on the newly advanced principle of an integral evaluation of group activity. This principle expressed the assumption, later confirmed by experiments, that rational selection of a group from among a number of vocationally suited candidates should be based on an evaluation of psychological interrelations that take place within a group during training and in carrying out assigned tasks. Special laboratory installations were required to conduct the experiments responding to this assumption.

The basis for these installations was F. D. Gorbov's observations of people taking a shower (with the water supply to each shower stall coming from a low flow hot water source). It was noted that if each of those showering adjusted the temperature of the water in his own stall so that he was satisfied with moderately warm water, the entire system rapidly reached a state of equilibrium. But if one man wanted to do things to his advantage, the entire system became unstable because of the responses by the others who suddenly found themselves showering in cold water.

The concept that derived from this observation, the concept of mutual, intersecting, ties, by means of which each of the members of the group, carrying out his own assignment, effected the progress made by the others, was used in installations known as homeostats.

Homeostats of this type (from three and more installations) are adjusted, interconnected, needle-type instruments. The mutual effect (the interrelationship factor) can be changed. The task is considered completed when all instru-

ments are on the specified position. Increasing the interrelationship factor makes the task more complicated, naturally. Certain complicated situations were reproduced in the control experiments with children of different ages, with /166 sportsmen, and with pilots, and different forms of emotional reactions were obtained.

Group psychology understands a homeostat to mean an installation, or an instrument, based on the principle of homeostasis, as well as on the principle that characterizes a system with the property of overstability. The group homeostat was considered to be a complicating form of contact and interrelationship within the group. These data were used to interpret certain psychopathological phenomena.

Always present in experimental group psychology has been the thought of psychological stress as a phenomenon to be avoided, or, conversely, reproduced for study. Once the method had been developed, and the requirements for conducting the experiments formulated (introduction of limitations and conditions), criteria for evaluating the strategy of the group as a whole, and the tactics of its members, were selected for purposes of obtaining comparable results [6]. Research methods were developed (change in the spatial location of the members of the group, their redistribution, creation of simultaneous and successive functional circuits, change in communication sequence, and others), conditions for dividing up the functions within the group and for appointing the leader were studied, criteria characterizing the state of training to trainability ratio, as well as critical situations of a stressor nature, were obtained.

The group experiments in which the membership of the group changed made it possible to study individual attributes more completely and in more detail that was the case when the individual was studied.

Hypothetical comparisons were made between the group as a whole and the individual in order to develop a thesis concerning the model-like nature of group experiments. Considered were certain forms of psychological stress expressed in the transition from the normal duality of cognition to morbid bifurcation (transport paranoiac, the Kandinskiy-Klerambo syndrome, and others), as well as treatment to prevent their development [8].

Group psychology received concrete application to long space flights within the framework of ecological psychology. The concept of the space field /167 of operation, reflecting man's minimum space requirement, was advanced. This concept was considered in connection with the organization of positions and the interiors of spacecraft, including rest spaces. The space field of operation has been established as a definite stressor.

3. Problems of Motivation and Emotional Reactions

One ought not overestimate the problem of motivation as a field of scientific research, applicable to space flights, despite the tremendous importance of motivation for the development of man's aspirations and activities. Here motivation appears in "pure" form, figuratively speaking, because what we are talking about here is something that for man is his whole life, coinciding completely with state, national, and, in the final analysis, with interests common to all mankind. The severe restrictions on the number of cosmonaut candidates, as compared with the number who have space aspirations, permit one to consider as insignificant the effect of factors such as these on motivation.

Data on the problem of motivation among cosmonauts (objective, and individual personality peculiarities) at this time do not define precisely principles of detailing and concretizing the selection of cosmonauts.

The concept of level of pretension, and the level of achievement, but in greatly modified form, can be used from the psychological point of view because the level of achievement here is a successful space flight, and the level of pretension is the realized possibility of completing it. Despite the coincidence of these two levels, the mismatch is unavoidable because of the disparity between the extraordinarily great capabilities the trained man has for making the flight, and the possibilities that he will win the honor.

The great psychological strain on the cosmonaut awaiting his flight should be the subject of consideration and description in its various aspects.

Emotional reactions and psychological stress in space flight on the surface is made up of two connected phenomena. One is the effect of space flight, the other the emotional reaction with its origin the unavoidable nervous shock, and, consequently, stress. Similar to this are the emotional reactions in

athletics that take place when the athletes are in training and when they are getting ready for the start, and considered to be the most rapid of the unfavorable phenomena interfering with mobilization readiness, just as the /168 emotions of waiting, nervousness, and others, are considered to be mental emotions with respect to space that must be suppressed in accordance with the "control yourself" formula. However, the emotional reactions accompanying the perception of what is taking place, the feeling of weightlessness, the view of the earth, the moon, the sky, unexpected lighting, and the like [1, 7], have been expressed in the cosmonauts' reports as expressions of the seen and experienced.

The evaluation of emotional reactions occurring in terms of type of deterioration in man's ordinary, peculiar emotiveness, was made for an earlier psychological diagnosis of the condition of fatigue, overtraining (reduction in the capacity to do light work, while retaining the capacity to do heavy work).

On the whole, a great many more, and different, investigations can be anticipated in connection with the problems indicated.

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CHAPTER 7 /169

OPERATOR TRAINING AIDS

Training aids are the set of devices designed for the vocational training of individual operators, as well as of all operating personnel in the "man - machine" system, under conditions close to actual conditions.

The term "trainer," which has been around for a long time, has been replaced by the more specific term "training aids." The refinement in the terminology in this case reflects the major qualitative changes that have taken place in recent years in the operator training system as a result of the achievements of engineering psychology and pedagogics.

Training aids are most effective when they become operational at the same time that the system proper does. The economic loss resulting from long delays in training aids becoming available is considerable.

1. General Requirements for Training Aids

The process of training operators by the use of training aids can be represented in the form of the functional schematic diagram shown in Figure 1. As will be seen from this figure, the diagram includes a controlling, and a controlled, system, as well as various devices and direct and feedback lines.

The controlling system connects the instructor (together with the equipment for analyzing the actions of the student and for developing the training algorithm), the device for developing the input information, and the equipment for reflecting that information. The other devices and lines form the feedback circuits.

The functional training diagram considered performs three functions: /171

develops the teaching information model;

controls the teaching information model according to the training progress;

monitors the actions of the student (evaluation of training effectiveness).

The concrete structure of the devices and units contained in the training aid is determined largely by the organization and procedures adopted for train-

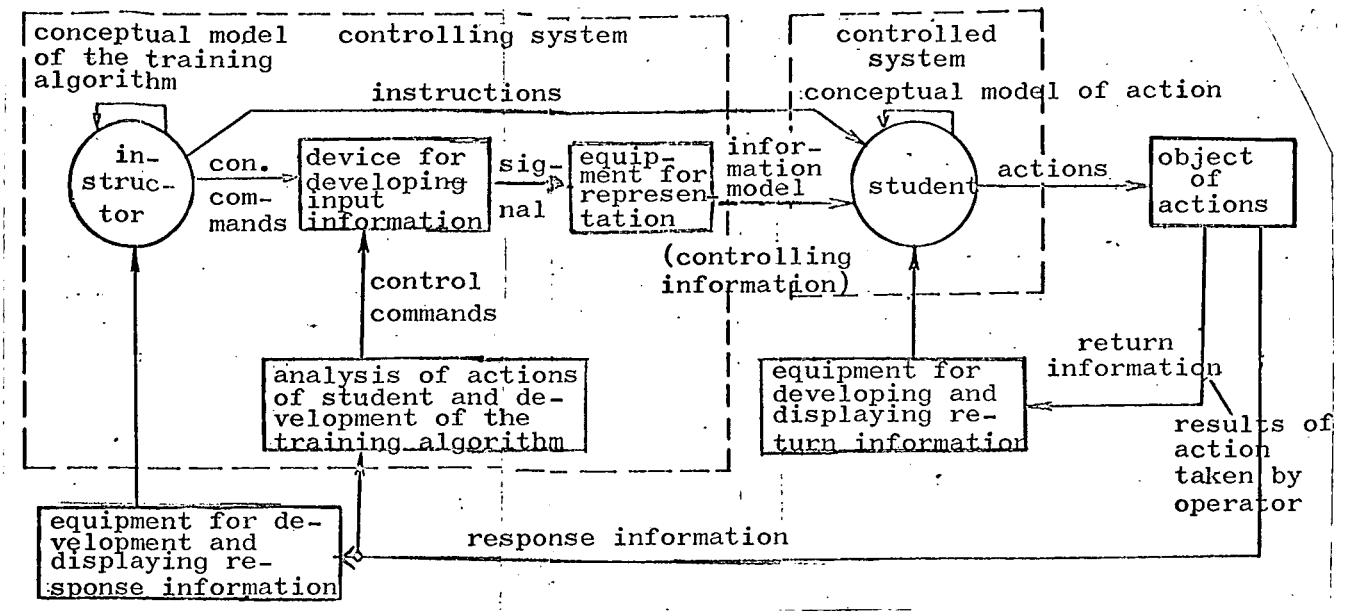

Figure 1. Functional diagram of the training of an operator using training aids.

ing the operators, and stems from requirements with respect to the teaching information model and the equipment for monitoring the level of operator preparedness.

The contemporary concepts of vocational training as a step-by-step process, controlled and monitored, make it economically advantageous, and pedogigically desirable, to build a set of training aids providing step-by-step training, rather than one type of training aid for training operators that copies exactly the real system in external appearance, structure, volume, and nature of information produced.

Needed for the first stage of vocational training, the "abstract" training stage, is a training aid that will bring out the individual, vocationally important, psychophysiological characteristics of the operator. The primary task during this stage usually is that of improving the indices for the psychophysiological and mental processes of the operator (speed, volume and accuracy of perception of information, volume of the operative and long-term memories, rapidity of solution of logical tasks of different degrees of complexity, speed and accuracy of motor reaction, and the like).

Needed for the second stage, the preliminary training stage, are training aids to develop specific conceptual models, and to bring out the complex of

interconnected operator actions, as well as the compensatory functions, in the process of developing complex sensomotor skills.

Needed for the third and fourth stages are training aids providing training under concrete conditions, as well as in complex and emergency situations. Training aids such as these aid in the final development and formulation of the optimum structure of the psychophysiological and mental functions of the operator (group of operators) needed for future work. /172

Particular attention should be given to the justification for the requirements for the teaching information model during the development of the engineering-psychological and pedagogical requirements for the training aid.

The teaching information model is understood to mean that set of simulated signals providing a sufficiently accurate display of the behavior of the object simulated in the training assignments. This results in limiting the system of stimuli needed to evoke from the student the actions required at the particular stage of the structure.

This concept of the purpose and properties of the teaching information model makes it possible to eliminate in many cases, the requirement for too great a degree of similarity between the real and the simulated information, particularly during the initial stages of the training.

The teaching information model should be similar to the real information model only to the extent necessary for rapid and qualitative formation for the operator of the stereotype and conceptual model of the actions corresponding to real actions. Models in training aids usually display the properties of an object over a wide range of changes in its parameters, and in all possible operating conditions, but reproduce only the information the operators receive when they are performing. The models ordinarily used in the training aid differ in structure and mathematical dependencies from the models constructed on the basis of a detailed description of the physical properties of the object, but are similar to the latter in their reactions to a limited class of controlling actions and outside disturbances.

The student starts his general acquaintanceship with the information model during the preliminary training stage, so the training aids used during this

stage should generate only the tentative bases for future actions, and display only the basic properties of the controlled objects.

The information model used in the training aids for the third stage of training should generate for the student control algorithms that are as accurate as the natural "variance" in operator actions.

The requirements for the completeness of the modeling of real processes in a training aid are formulated from an analysis of the volume of information needed by the operator for the control algorithm. All information received by /173 the operator when controlling the real object will be subject to analysis. What must be borne in mind when making the analysis is that there are many cases when there is an excess of information during the functioning of real systems, and this excess is not used by the operator.

The evaluation of the required accuracy of reproduction of the information model is made on the basis of a combined analysis of the capabilities of the means for providing the formation of the real information model and the algorithm for operator actions, the purpose of which is to determine the influence of the information displayed on the formation by the operator of the required skills. The capabilities of the operator to control this process are established during this type of analysis.

The data needed to reproduce the information model can be made up by the instructor (or by an automatic device) in the form of discrete, or continuous, signals at different levels, with, or without taking the controlling actions of the operator into consideration, depending on the possibilities indicated.

The final determination of model accuracy is made experimentally. Ideally, the experiment should be conducted as follows.

A series of "correct" controlling actions are taken in a real system, or are made to its complete model, and the controlling actions by the operator are recorded. The data obtained then are used to determine the characteristics of the law for the distribution of these actions (mathematical expectation and dispersion). The following can be used as the indices for the controlling actions:

time of transition process;

integral indices of control quality;

number of switchings of controlling actions;

amplitudes of controlling actions;

time intervals between controlling actions;

coefficients of the polynomial approximating the controlling function.

The sequential simplification of the system model follows (reduction in order of equations, partial linearization, approximation of complex ratios, less refinement of coefficients of equations, and the like), and the controlling actions of the operator are recorded. If the indices of the controlling actions correspond to the range of changes in similar indices, obtained during "correct"/174 controls to the complete model, or real system, these simplifications can be considered acceptable.

The following can be used as the auxiliary data that are taken into consideration in the training aid when responding to the question of the necessary accuracy for modeling real processes:

statistical data characterizing the scatter in the parameters of the different models of systems when mass produced;

errors in the transition devices, instrumentation, and automatic regulation and control systems.

Summarizing, it should be pointed out that in staged training the content of the teaching information model, and the behavior pattern of its changes, depend primarily on the pedagogical tasks of each stage, procedures, and training algorithm. The main thing, then, is to consider the requirement of similarity between the simulated information model and the real one, as well as the requirement for correspondence between the teaching information model and the necessary conceptual model. This approach results in a more correct determination of the accuracy required in reproducing the signals, as well as of the necessary volume and flow of information simulated in the training aid. The accuracy with which the signals are reproduced is chosen on the basis of an objective evaluation of the level of advancement of the student, and the volume of simulated information on the basis of some excess of capability on the part of the operator (overloads) during his training to take actions in emergencies.

It is undesirable to reproduce a "precise" structure and the characteristics of a real information model not reproduced by man. For example, in the

case of simulation of dynamic objects, there are many cases when high order terms can be eliminated from the differential equations modeled in the training aid without danger to the skill formation process.

It is very useful to have an adjustable time scale in the training aid when teaching how to control high-speed processes, as well as under the conditions that prevail when the situation is changing slowly.

The teaching information model with a "fixed" program should be avoided in order to ensure that the effect of newness will be injected into the training, as well as to make it possible to put the student under problem situation conditions. As a matter of fact, operators quickly recall variants in the simulated situation, and a program such as that mentioned usually has only one /175
course of action that the operator can take, and this limits the possibilities for creative decisions.

Training aids in which the source of data for reproducing the teaching information model is a tape are examples.

Continuous monitoring of operator actions and decisions is a necessary condition for successful operator training. The speed at which physical processes take place in modern systems, the complexity of the information models, the presence of several approaches that can be taken by the operator, as well as the need for statistical processing of the results of individual actions by the students, require that the training aid include special devices for monitoring instruction and controlling the training process.

System characteristics, and the purpose for which the training aid is intended, determine special requirements for reproduction of the interior, mock-ups of the position (external appearance of the control consoles, internal equipment, and dimensions of the space), and sanitary and hygienic conditions (temperature, humidity, lighting, noise, physical fields, and the like). In the case of training aids designed to perfect the operator's psychophysiological (and mental) processes, the interior can differ from the real interior and need only satisfy the conventional standards of engineering psychology, but in those designed to form vocational skills and ability, the external appearance of the consoles should match that of the real consoles. Only those devices that are part of the internal equipment of the real system and that have

a direct bearing on operator activity, or limit the receipt of external information and the sphere of operator activity, need be reproduced.

The sanitary and hygienic conditions should satisfy standards for training spaces. However, if the training aids are designed for operator fatigue training, and for checking his dependability under normal and stress conditions, the possibility of reproducing real sanitary and hygienic conditions must be anticipated.

2. Classification of Training Aids /176

The growth that has taken place in the equipment installed in enterprises and industrial plants, and the appearance of new types of transportation and communication, have given rise to the need to develop a great many different kinds of training aids.

Lack of a unified training aid classification system, and of the corresponding standards, have had a negative effect on the system used to train cadres for a wide variety of specialties.

Standardization of the individual elements, and the overall structure, of training aids will make it possible to:

establish unified specifications for the structural arrangement of training aids, and of their elements;

standardize the training equipment for typical systems used in the different branches of the national economy;

reduce the time required to develop training aids, and reduce the cost of manufacturing them;

provide savings in material and technical resources for expensive systems in the process of training operators;

simplify the system and reduce training time, as well as to increase the effectiveness of the training.

One of standardization's primary tasks is that of developing unified training aid classification. Classification should be based on a logical breakdown of all training aids into separate groups by observed similarities and differences. A group customarily is defined by listing the training aids included in the group, or by designating the criterion, or criteria, inherent in each member of the group, and lacking in representatives of the other groups.

Each group, in turn, can be broken down into subgroups, and two, or several, groups can be combined into a common group, or class.

The classification criteria are not selected arbitrarily. Here a decisive factor is social-historical practice permitting the development of criteria characterizing the social significance of the elements of multiplicity of objects studied according to the presence, or absence, in theme of particular properties, and criteria. In so far as they are applicable to training aids, these criteria should characterize the organizational and pedagogical potentials of the training aids, as well as their engineering and cost factors.

An analysis of the different approaches that have been taken to training /177
aid classification reveals that the approach with the greatest practical advantages is that based on the use of the criteria indicated (as compared with classification of devices in terms of peculiarities of the processes used to train operators for concrete systems).

The most significant criterion, establishing the organizational potential of the training aids, is the degree to which they are linked with the real equipment in those systems for which the operator is being trained. Based on this criterion, training aids can be broken down into self-contained, built-in, and associated.

Self-contained training aids are specially developed and manufactured devices designed for training operators without using real systems. Training aids such as these contain real operator positions, or mock-ups of them, in addition to the devices for forming input information, and the monitoring equipment. Self-contained training aids are most widely used in special schools and centers that train operators. Figure 2 is a generalized schematic diagram of self-contained training aids.

Built-in training aids are a component part of a real system. They are functionally and structurally associated with it. They have common units for forming the information models, common kinematic and switching lines, and the like. Built-in training aids make it possible to train operators right at their positions in the system.

The associated training aids, as distinguished from the built-in ones, are structurally independent devices that can be connected into real systems. Asso-

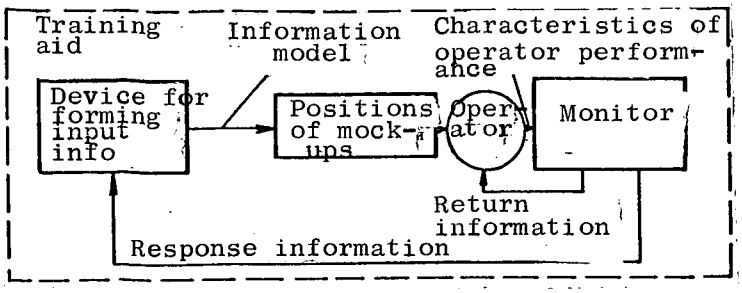

Figure 2. Generalized schematic diagram of self-contained training aids.

ciated and built-in training aids /178 make it possible to train operators right at system positions. Associated training aids can be made portable so they can be used to train operators in several identical systems. Neither type requires special training positions, and can be made to conform to the diagram shown in Figure 3.

The use of associated training aids opens up broad possibilities for standardization and unification because the same types of devices can be used in training aids designed for different purposes. One example of devices such as these is the target coordinate transmitter in the training aid for training operators to handle different types of radars, the design of which does not depend on the particular type of radar. Another example of standardized devices is the equipment for recording, processing, and analyzing operator performance time characteristics.

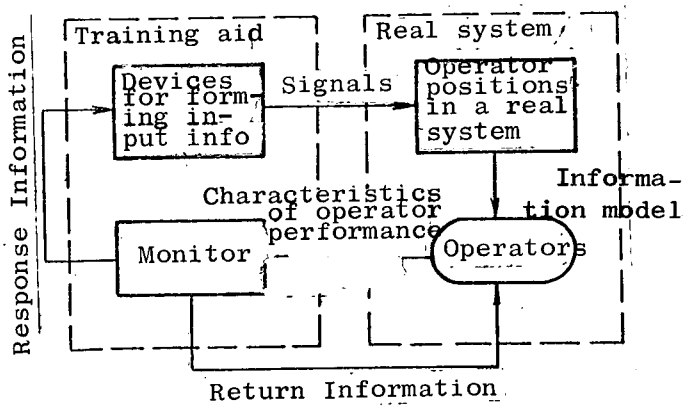

Figure 3. Generalized schematic diagram of associated training aids.

Another advantage of the built-in, as well as of the associated, training aid is the possibility of training the operators at positions located within real systems. This is particularly important when training aids are used to train operators standing a continuous watch.

An indisputable advantage of these training aids is that the technicians operating the system must come to work on it at the same time that the operators are undergoing training, and this results in a more profound study /179 of the peculiarities of system operation under different conditions, including emergency ones.

A disadvantage of built-in and associated training aids is that real system resources must be used to train operators.

The most frequently used criteria determining the pedogogical capabilities of training aids are the completeness with which all possible situations are reproduced, and the degree to which system operating personnel are involved.

In accordance with the first criterion, training aids can be specialized, and complex.

Specialized training aids are designed to train operators to perform individual elements of activities (track signals, separate signals from the noise background, and the like), or to develop in them individual job skills.

Complex training aids are used to train operators to perform vocational activities within the full scope of their functional duties.

It should be noted that specialized training aids usually are self-contained, whereas the complex ones can be self-contained, associated, or built-in.

Training aids can be broken down into individual and collective in terms of the degree to which system operating personnel are involved in the training.

Individual training aids are a set of devices designed for training operators singly. Equipment for training radio telegraphers in aural reception, in sending, and the like, for example.

Several individual training aids sometimes can be connected to provide single training to a group of operators simultaneously in performing the same functional duty. In this case, one device for forming the input information can be used to simultaneously transmit to all positions, and the individual monitors of the training process can be concentrated at the instructor's position. This makes it possible for one instructor to control the training process for several operators. An example of connected training aids is the classrooms used for training radio telegraphers.

Similar training aids can be used for training in an individual sequence, and many students can be trained at the same time while so doing. Training aids used in this way sometimes are called individual-mass, or mass, training aids.

Collective training aids are designed to train operators with different /180
job descriptions who interact with each other in the performance of their func-

tional duties, and to do so simultaneously and jointly. Unfortunately, the technical literature often confuses the concept of complex and collective training aids, despite the fact that there are significant, fundamental, differences between them.

The potentials of collective training aids are quite varied, ranging from the development of stable psychophysiological skills in individual and group activities among operators operating a specific object, to training them to control large systems comprising a great many different, complex, subsystems.

Collective training aids designed to train a group of operators performing identical functional duties that require intercoordinated actions in real systems are called group training aids.

Individual training aids are used most often in the form of self-contained training aids, whereas collective training aids are used in the form of built-in, or associated aids. This can be explained by the fact that self-contained collective aids require reproduction of job site analogs, equipment for information processes, equipment for forming and displaying the information models, and other equally complex elements of real systems. In other words, self-contained collective training aids require virtually complete repetition of the real system, and this, in many cases, is undesirable.

One of the classification criteria should characterize the cost and engineering features of the training aid, as we already have pointed out. The following ones of the many criteria of these features will be considered:

the method used to assign input information;
the method used to form the teaching information model;
capabilities of the monitor;
transportability.

Training aids can be broken down into unilateral and game (multilateral), according to the methods used to assign input information.

In the case of the unilateral training aids, the input information is assigned by the instructor in accordance with the program and objective indices for developing the training process. The conditions of the assignment usually do not change before final solution.

Game training aids reproduce the conditions of the assignment and the actions taken by the sides in game situations. A variant of a generalized structural scheme for training aids such as these is shown in Figure 4. The response information in this particular case is used as controlling to change the corresponding information models for the sides participating in the game. /181

Training aids can be broken down by the method used to form the information model into those creating the information model by using simulator-modeling devices, and those doing so by using physical analogs.

The simulator-modeling devices forming the information models can be used when the operator is not in direct contact with the object on which the system he is controlling is acting. Different electronic, electrical, or mechanical devices can be used to form the information model in this case. An example of the simulator-modeling device is the radar echo signal simulator.

Physical analogs can be used to form the information model if the operator in a real system can observe the object subject to the effect of the system he is controlling. Examples are training aids used to train drivers, and in which special motion pictures are used to create situations requiring actions on the part of the student that are very close to the real actions required by the particular situation shown on the film.

Training aids can be broken down into those with automatic and nonautomatic monitoring of the actions of personnel being trained, depending on the monitoring capabilities of the equipment.

Training aids with automated monitoring in turn can be broken down into the following types according to the nature of the response and return information:

those with complete response (return) information;

those with incomplete response (return) information;

those with binary response (return) information (based on the "true-false" principle).

Training aids with binary response (return) information can be included with those with incomplete response information. But because of the specificity of binary information, and the special features of the methods required for the

technical realization of such equipment, it is desirable to put these training aids in a separate group.

The complete response information can be used in the training aid with automated monitoring to automatically evaluate the results of the different stages of training and the formation of the program for further training. Training aids with these capabilities can have automatic, or forced, reprogramming.

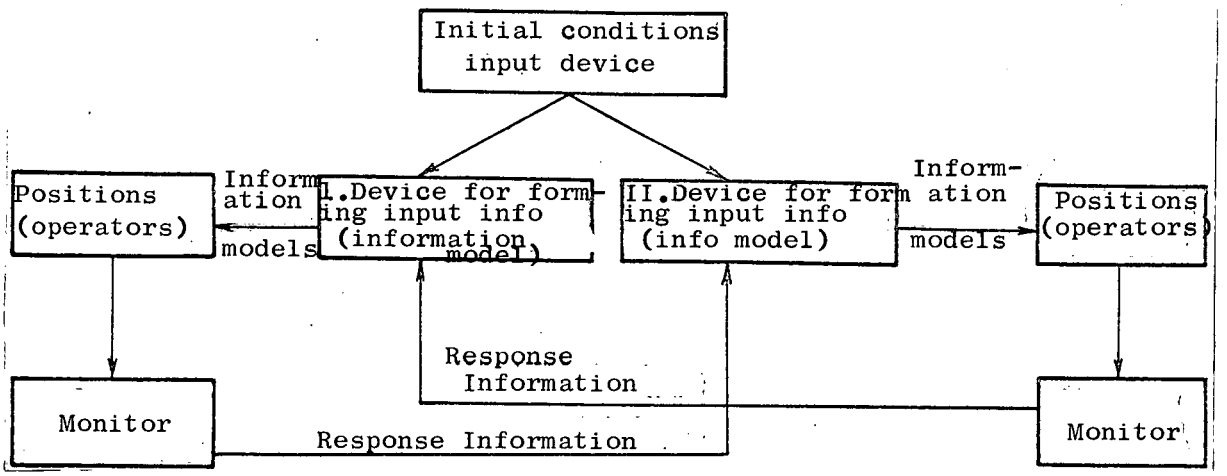

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Figure 4. Variant of a generalized scheme for game training aids.

In the former, the adaptive training aids, the training program automati- /183 cally accomodates to the capabilities and the level of preparedness of the operators. The training program is corrected by the instructor when the training aids have forced reprogramming.

Reprogramming is on the basis of analysis of past performance by the operator and involves selection of those working conditions that require from the operator a continuous increase in the intensity of his actions. The maximum level of intensity of his actions should correspond to actions that are real possibilities in the future.

In terms of transportability, training aids can be fixed, and mobile (transportable or suitable for carrying). Specialized classrooms in schools and plants are the most characteristic examples of fixed training aids.

In principle, all self-contained training aids can be built as fixed installations, installed in special spaces. In such case the devices for forming the input information and the monitors are not part of the operators' positions, but are located elsewhere.

Built-in aids for training operators of moving systems sometimes are referred to as on-board training aids. So far as the associated training aids are concerned they are made mobile for mobile systems, and fixed for fixed systems, without precluding the possibility of making them mobile.

The training aid classifications cited are not exhaustive, of course. There are other distinguishing criteria that could be used to classify them. In particular, the classification could be based on the hierarchical principle, with the classification criteria for the individual elements considered in terms of their objective, economic, technical, design, and other features. This sort of classification can be extrememly useful for purposes of standardization of these elements for mass producing training aids for different branches of the national economy. Bear in mind that a training aid classification based on the hierarchical principle can have practical value only after the introduction of the corresponding state, or branch, standards. /184

3. Generalized Typical Structural Arrangement of the Training Aid

The structural arrangements of the training aids are determined primarily by their purpose, by the training method adopted, and by the concrete type of system for which the operator is being trained. So training aids for training radar operators differ in structure from training aids for training pilots for the Civil Air Fleet, and the latter, in turn, have little resemblance to training aids for training electric power net operators, etc.

Nevertheless, there are typical units and links that it is mandatory to have in all the different classes of training aids. The set of similar devices is a generalized, typical, structural arrangement of the training aid. It includes the following elements:

devices for assignment of input information (devices for reproducing the teaching information model);

models of positions for operators, or devices for coupling the training aid with the indicated elements of a real system;

equipment for documenting and for monitoring objectively the level of operator training;

models of individual elements of the real system;

a system for controlling the training aid from the instructor's console.

Let us consider the peculiarities of building these elements, as well as the requirements they must satisfy.

Devices for Assignment of Input Information

These devices are designed to simulate input actions on indicators with which the operator interacts while doing his job. The list, and the range of change, in the input actions are determined by the characteristics and conditions of system functioning.

The devices for assignment of input information should provide:

reproduction of input information in the volume determined by the training system;

the assignment of unified input information to all indicators at the positions of operators undergoing training, and to the instructor's console;

the necessary degree of approximation of the reproduced conditions to /185 real, determined by the purpose for which the training aid is intended, and by the operator training tasks;

flexible control of the information inputs, and their operative change during performance.

In most cases the operator is interacting with the information models of real processes, or of physical objects, rather than with the latter proper, so the equipment for assigning the input information is a device for forming the teaching information models of the real processes, or objects, and ordinarily includes computers, converters, and devices for forming the displayed information. The computers are designed to solve differential equations describing the real physical processes taking place in the "external object - indicator" system, or to solve kinematic equations of object motion in the same system. The solution of the equation should be arrived at with consideration having been given to the deterministic and random components of the parameters of real processes, modeled with the help of analog devices.

Modeling of real processes in the training aid can be complete, incomplete, or approximate, depending on the operator's training assignment [6].

The following relationship between the parameters of the model, x_i, and the original, y_i, is provided in the case of complete modeling:

$$x_i = m_i y_i,$$
$$y_i = \varphi(y_1, \ldots, y_K; x, y, z; t), \quad (1)$$

where

m_i is some scale factor;

y_i is the present basic parameter of the process;

x, y, z are present coordinates of moving objects;

t is time.

Incomplete (local) modeling provides only similar base parameters, but the process is considered in terms of time only

$$y_i = \varphi_1(y_1, \ldots, y_K; t) \quad (2)$$

or in terms of space only /186

$$y_i = \varphi_2(y_1, \ldots, y_K; x, y, z). \quad (3)$$

Similarity of parameters can be lacking in the case of approximate reproduction of real processes; that is

$$x_i \neq m_i y_i, \qquad x_i \simeq m_i y_i. \quad (4)$$

Naturally, reproduction in accordance with the conditions of Eq. (4) is permissible only when the individual parameters of a real process have little, or no effect, on the conditions under which the information model presented to the operator is formed.

The computers used in training aids can be built on the basis of analog, or computer, techniques. The selection of the computer is determined by the accuracy required in reproducing the parameters of the real processes in the training aid, as well as by acceptable costs. The quantitative relationship between relative cost of the computer, or analog device, and the accuracy with which the parameters of the model must be reproduced, is shown in Figure 5 [13].

If the information on real processes must be reproduced for several operators at different positions, identity of such information must be provided. /187 The easiest way to do this is to install one computer in the training aid and connect it to all positions. Signal formers, which convert the input informa-

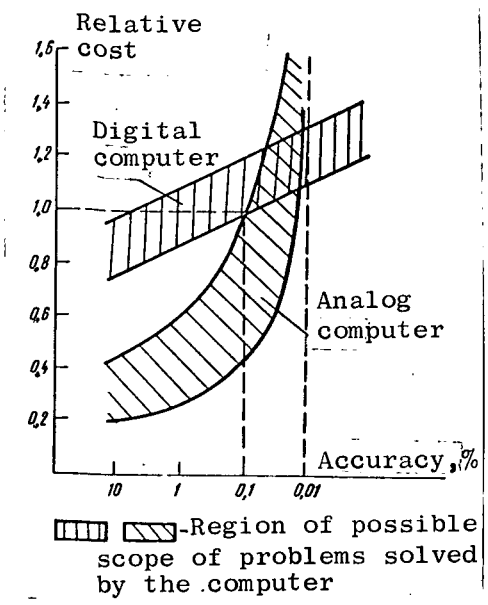

Figure 5. Relative cost of computers and analog devices used in training aids to create the teaching information models in terms of the accuracy required in their reproduction.

tion calculated by the computer into the signals needed for normal operation of the service equipment for displaying this information, are used in training aids to match the information reproduced by the computer with the indicators at the operator's positions. The coded signal to the forming devices can be represented in general form as

$$S' = S'(t, x_i), \tag{5}$$

where

t is present time;

x_i is the parameters of the process, determined in accordance with one of the equations, (1) through (4).

The signal at the output of the device for input information assignment will have the following form when coding takes random components into consideration

$$S = S'(t, x_i) + \mu_S(t, x_i), \tag{6}$$

where

$S'(t, x_i)$ is the deterministic component;

$\mu_S(t, x_i)$ is a random signal component.

A typical block diagram of the device for input information assignment will include the following elements (Figure 6):

a unit for assignment and input of initial conditions;

a resolver;

a random processes generator;

a coder;

signal former units;

lines for controlling programmed reproduction of information.

The instructor puts the initial conditions x_0, y_0, z_0, t_0, and the like, and the program for the concrete problem, in the assignment unit. These data are the original data for calculating the parameters of the reproduced process.

The calculated parameters are used for coding and forming the signals, $S_i(t, x_i)$, fed into the data processing channel and to the indicators as the original displays of the external actions.

The computer and the devices for forming the signals thus form the so-called simulator elements in training aids.

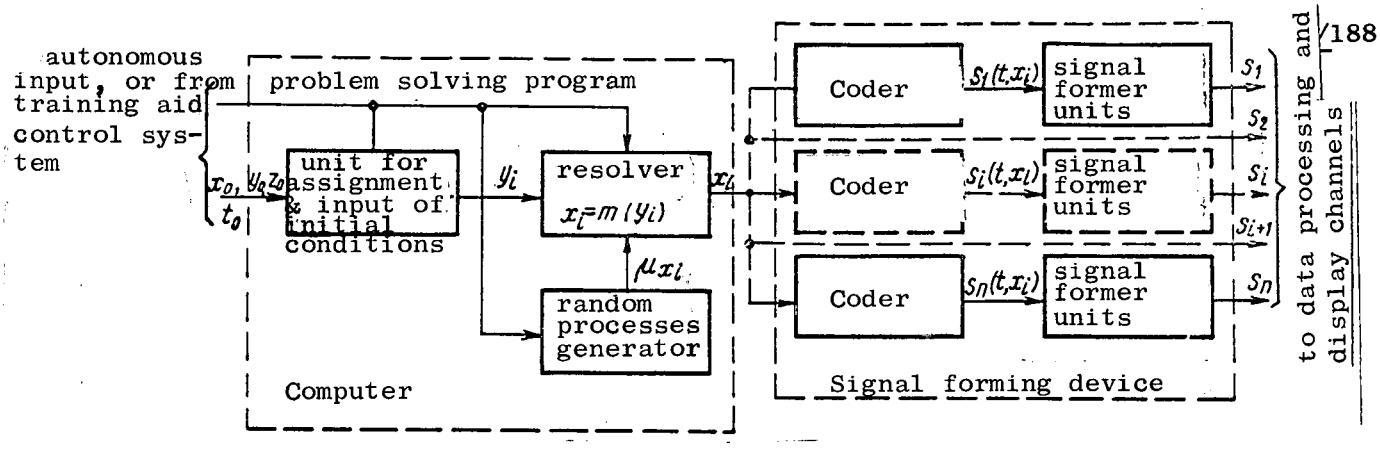

Figure 6. Typical block diagram of a device for input information assignment.

Operator Position Model

/189

The operator position model provides the means for reproducing the controls, the indicators, and the signal processing channel for obtaining input information in the form, and volume, needed by the student to learn his job under all operating conditions, in the form of a training aid.

A typical block diagram of an operator position model is shown in Figure 7. It functions as follows.

The initial data on a concrete study situation, in the form of signals, $S(t, x_i)$ are fed over the signal processing channel to the display, which reproduces processes and phenomena similar to those the operator will encounter under real conditions.

The information model of the external situation thus reproduced is perceived by the operator and evokes responsive action in accordance with the job

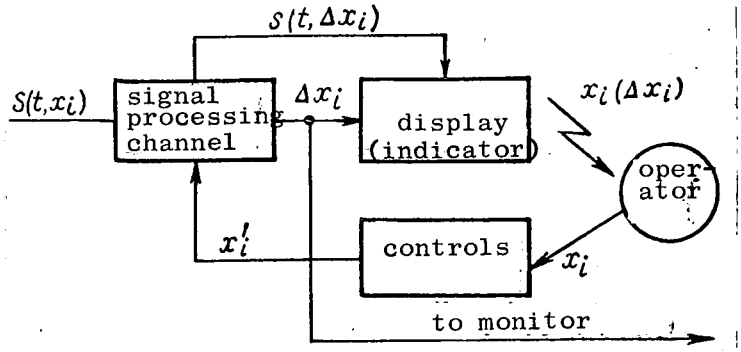

Figure 7. Typical block diagram of an operator position.

algorithm he has studied. The operator's actions, x_i', are fed by the controls to the signal processing channel and change the content of the information model at the displays. This change is caused by some controlling signal, $\Delta x_i = x_i - x_i'$, obtained as a result of the operator's reaction to the external action.

The built-in and associated training aids do not have operator position /190 models because the operators are trained at positions in real systems. These training aids include special devices providing for the delivery of simulated input information to the channel for processing the signal for the real system.

The qualitative and quantitative characteristics of operator performance in the "operator-training aid" system are fixed by the documentation instrumentation, including the devices for recording and monitoring the level of training.

Instrumentation for Documentation and Objective Monitoring of Level of Advancement of the Operator

Instrumentation is provided for forming and fixing the information needed to determine the level of advancement of students in accordance with the monitoring and information method adopted, and presented to the student over the feedback line so he can make operational corrections to the errors he is permitted. This instrumentation comprises the so-called monitoring section of the training aid, and usually includes devices for:

documentation;

analysis of time and accuracy characteristics of action;

forming and displaying response information;

forming and displaying return information;

Documentation devices automatically record parameters characterizing the performance of the operator (tracking errors, accuracy in reading meters, time to perform the operation, and the like). The scope of recorded parameters is determined by the system of evaluations and indices adopted in the training

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procedure. Documentation devices should provide for repeated reproduction of recorded information on a real time scale during training, as well as after it, in a form convenient for analysis.

Parameters characterizing the work of the operator, and subject to documentation, can be conveniently combined into the following groups:

voice signals and commands;

parameters determined by two discrete conditions, "yes - no" (cut in - cut out toggle switches, pushbuttons, and the like);

signals in the form of slowing changing functions of time (errors in /191 tracking, manual control, and the like).

Ordinarily used to document the parameters in the first group are (Figure 8a):

microphone (throat microphone) pickups installed at points in the voice signal circuit;

the mixer-amplifiers;

accumulators (tape recorders, most often);

reproducers.

Used to document the parameters in the second group are (Figure 8b):

built-in pickups;

discrete signal coders;

amplification and matching devices;

devices for recording signals;

decoders and reproducers.

Used to document the parameters in the third groups are (Figure 8c):

built-in pickups in the signal circuit;

devices for separating operator errors;

devices for recording signals;

reproducers.

The devices used to record signals in the second and third groups can be made up of elements used in magnetic tape recording techniques, or from among those used in analog or computer techniques.

The devices for separating errors perform a series of mathematical operations usually associated with the calculation of:

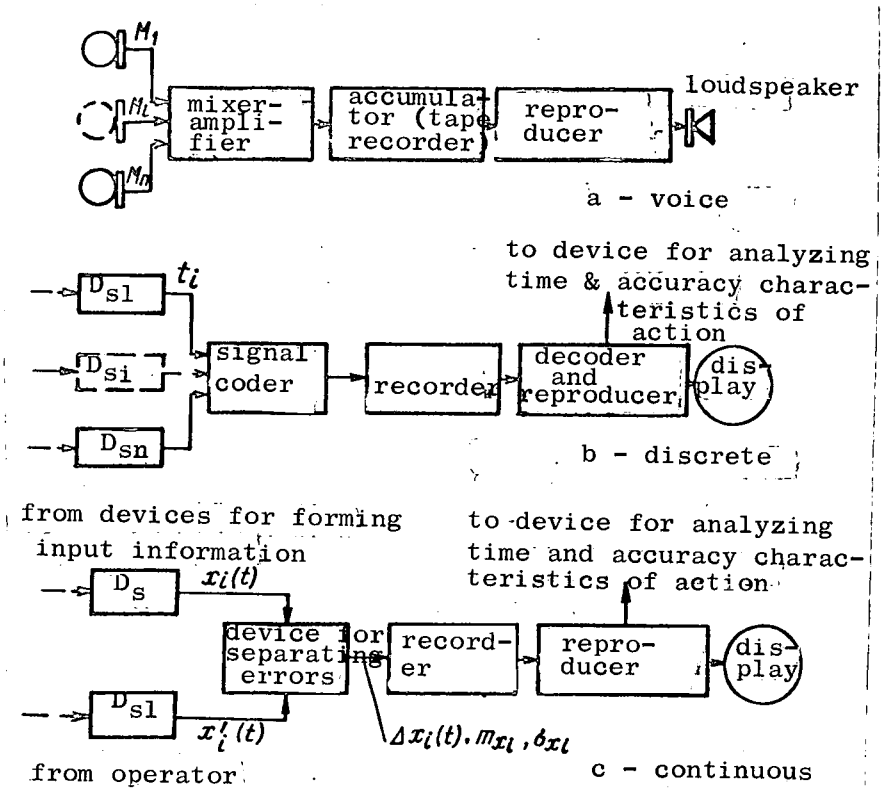

Figure 8. Block diagram of signal recording devices.

the instantaneous value of the error as the difference between the value of the present coordinate of the target, $x_i(t)$, and the value of the coordinate generated by the operator, $x_i'(t)$, that is

$$\Delta x_i(t) = x_i(t) - x_i'(t); \tag{7}$$

the statistical characteristics of the errors (the mathematical expectation and the root-mean-square value)

$$m_{\Delta x_i} = \frac{\sum_{i=1}^{n} \Delta x_i(t)}{n}, \tag{8}$$

$$\sigma_{\Delta x_i} = \frac{\sqrt{\sum_{i=1}^{n} [\Delta x_i(t) - m_{\Delta x_i}]^2}}{n-1}, \tag{9}$$

/192

where

n is the number of readings of the magnitude Δx_i.

The dependencies in Eqs, (7)-(9) also can be used to calculate the statistical characteristics of the time required to carry out the different operations.

Analysis of time and accuracy characteristics of action can be used to determine special and general indices of the quality with which the operator (or group of operators) does his job. /193

If tracking errors are included in the special indices, for example, they are calculated using Eqs. (7)-(9) in the analysis of time and accuracy characteristics of operator actions. In practice, however, it is more convenient to use certain generalized indices to evaluate the level of advancement.

One such index of the level of advancement can be the probability that the operator (or group of operators) will carry out the assigned task. This index can be formulated as follows for concrete monitoring conditions:

when time to complete the operation is being monitored - the probability that the time required to complete the operation will not exceed the time specified;

when accuracy of performance is being monitored - the probability that the error in the reading (in tracking) will not exceed the error specified;

when logical (heuristic) actions are being monitored - the probability that the number of error-free decisions made during the performance will at least be at the specified level.

Very simple mathematical apparatus can be used to calculate these indices. The probability that the assignment will be carried out is calculated in this case as the ratio of the number of correctly solved problems to the total number of realization. Then the algorithm for the evaluation of the level of advancement in this particular case, for the evaluation of the effectiveness of the work being done by the operator, can be represented as shown in Figure 9. Figure 10 is a variant of the block diagram of a device for evaluating the readiness of the operator in terms of the time he takes to carry out the assignment.

The calculated values of the indices (or evaluations) are presented to the student continuously, and automatically, by the device for forming and representing response information in order to refine the training process. There are many cases when it is desirable to record the indices obtained on paper or mag-

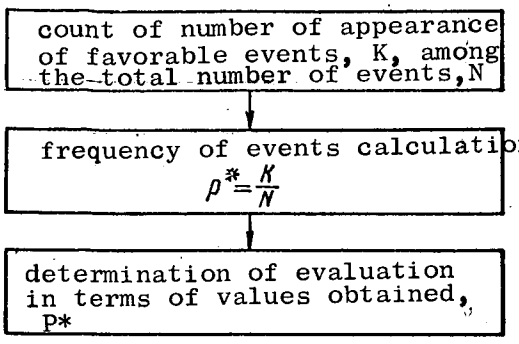
count of number of appearance of favorable events, K, among the total number of events, N
frequency of events calculation $p^* = \frac{K}{N}$
determination of evaluation in terms of values obtained, P*

Figure 9. The algorithm for evaluating the effectiveness of operator performance.

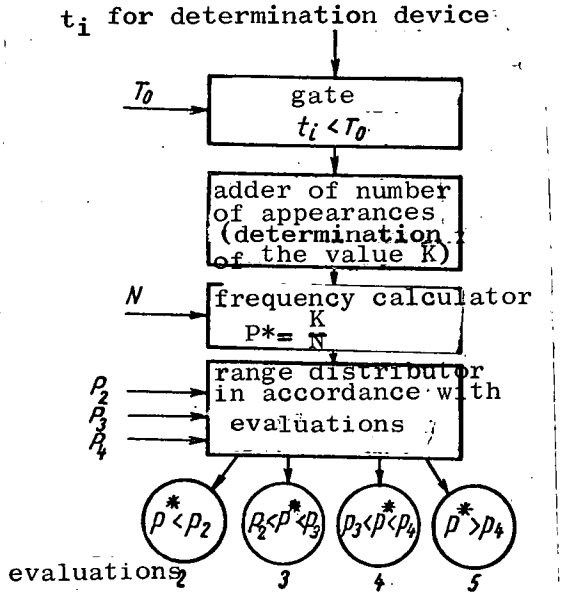

Figure 10. Block diagram of a device for calculating evaluations in terms of time spent by the student in carrying out the operation.

netic tape for retention as a permanent record. The device for forming and representing response information is located near the training aid control console and includes necessary indicators, displays, and other elements.

The devices for forming and representing return information convert the output signals from the devices for analyzing time and accuracy characteristics of actions into a form convenient for displaying them to the student. The return information plays the part of prompting, and is absorbed by the student simultaneously with the recording of errors in /194 his actions and the taking of operational measures to eliminate them. Return information is a learning stimulator in this sense. The return information circuits usually are built with information feedback systems, and provide for the supply of [10]:

discrete information, on "yes-no" and "true-false" principles; /195

complete information, with an indication of the magnitude and sign of the error in operator performance.

Figure 11 shows the structural diagram of information feedback in a training aid. The documentation equipment records real, x_i', and standard, x_i, actions by the operator. The latter are supplied by a special computer in the training aid. Operator error, $\delta_{xi} = x_i' - x_i$, is calculated in the device for forming the return information, and is fed to the device for displaying the return information and is perceived by the operator in the form of an additional mismatch.

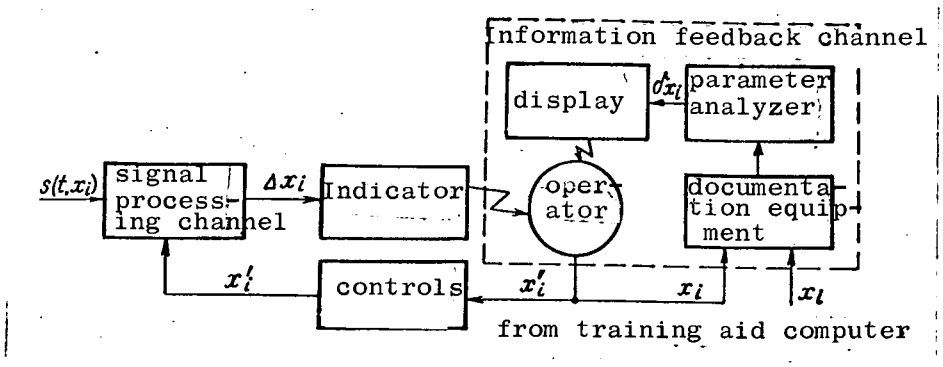

Figure 11. Schematic diagram of how information feedback is used in a training aid.

Since the resolution of the additional indicator can be selected to be much better than the resolution of the main (the working) indicator, perception of the error, δ_{x_i}, in the feedback channel is easier, as compared with perception of the error, Δx_i, in the direct channel. The operator repeats the operation when the error δx_i exceeds the specified value.

Thus, in a system with information feedback any noncorrespondences (distortions, and the like) occurring in the direct channel can be observed unfailingly by the operator, and can be eliminated (or reduced) by repetition of the exercises. This important quality of a system with information feedback results in a significant reduction in time required to train operators and in raising the level of advancement of operators.

The devices presenting the return information usually are located at the operators' positions.

A typical block diagram of the monitoring section of a training aid is shown in Figure 12. Also included in this diagram are the connections between the monitors and the other elements of the training aid.

Models of Individual Elements of the Real System /197

Models of the individual elements of a real system included in the training aid provide:

reproduction of the actions of the real system on the activity of operators;

simulation of individual elements of a real system, the participation of which is mandatory under certain training aid operating conditions.

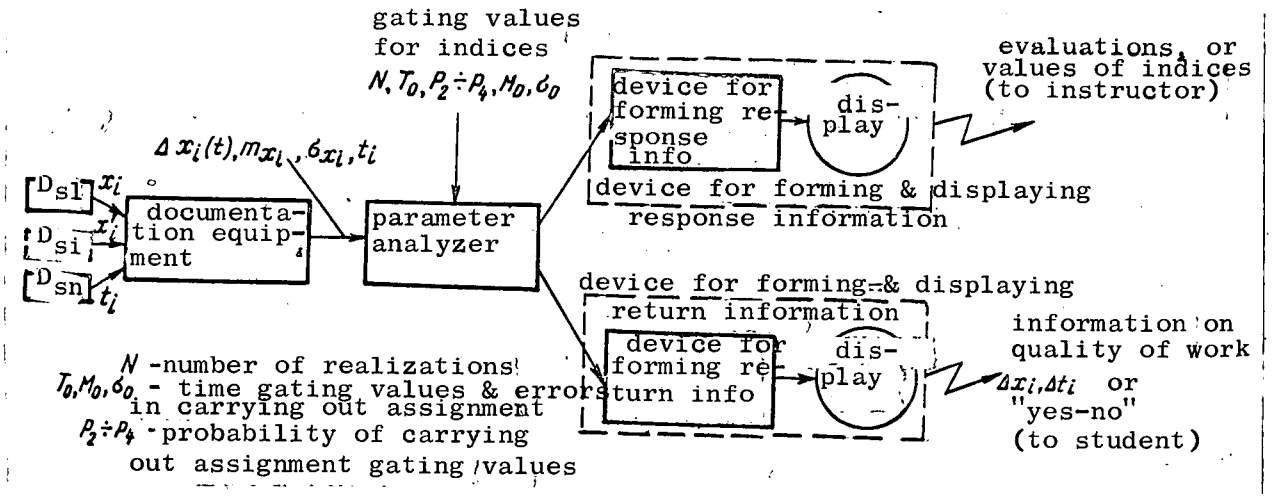
gating values for indices
$N, T_0, P_2 \div P_4, M_0, \sigma_0$
$\Delta x_i(t), m_{x_i}, \sigma_{x_i}, t_i$
D_{s1} x_i
D_{si} x_i
D_{sn} t_i
documentation equipment
parameter analyzer
device for forming response info
display
evaluations, or values of indices (to instructor)
device for forming & displaying response information
device for forming & displaying return information
device for forming return info
display
information on quality of work
$\Delta x_i, \Delta t_i$ or "yes-no" (to student)
N -number of realizations
T_0, M_0, σ_0 - time gating values & errors in carrying out assignment
$P_2 \div P_4$ - probability of carrying out assignment gating values

Figure 12. Typical block diagram of the monitoring equipment in a training aid.

In the first case these models provide a closed performance cycle for operators during their training, from the time the input information on the status of the object of control is received until the performance cycle is completed. In the second case they make it possible to eliminate some of the elements of the real system from the equipment during training. For example, there is no need to include the controlled system when the operators are being trained to control a subsystem. Here it is sufficient to replace the controlled system with a very simple model that will reproduce its output parameters.

System for Controlling the Training Aid from a Console

This system is for the instructor, and is designed for remote (manual and programmed) control of the operation of the simulator and monitor. It provides control of:

the parameters of the input information as applicable to any variant of the information model;

the training aid operating modes - "selection," "instruction," "practice," "monitor," as well as individual, or group, training modes;

the monitor in the different training aid operating modes.

All training aid controls usually are concentrated in a single console for the instructor and the console is equipped with devices for displaying the response information, training aid controls, and signal components.

/198

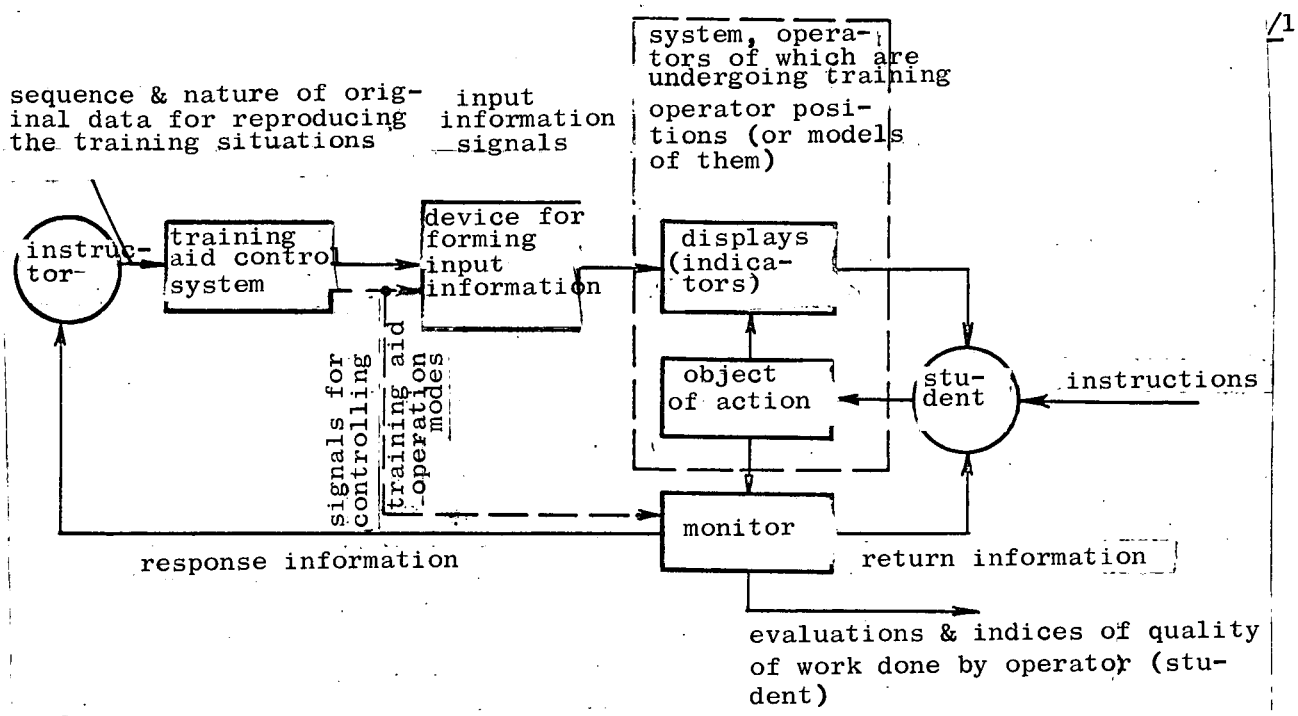
system, operators of which are undergoing training
operator positions (or models of them)
sequence & nature of original data for reproducing the training situations
input information signals
instructor
training aid control system
device for forming input information
displays (indicators)
object of action
student
instructions
signals for controlling training aid operation modes
monitor
response information
return information
evaluations & indices of quality of work done by operator (student)

Figure 13. Generalized structure of a training aid schematic diagram.

The set of typical elements considered above form the typical structural /199 scheme of the training aid (Figure 13). The training aid built on this scheme provides a complete operator training cycle.

Training aids can differ from the typical scheme considered in each concrete case, but the absence of even one element of this system will result in a significant reduction in their potential.

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CHAPTER 8

/201

MATHEMATICAL MODELS OF TRAINABILITY OF THE OPERATOR IN THE "MAN-MACHINE" SYSTEM

The creation of a scientifically based system for training operators requires the establishment of quantitative relationships between factors determining to some particular degree the effectiveness of operator actions. These relationships, given in many papers as "mathematical models of trainability (teaching, instruction)," or as "curves of trainability (teaching, instruction)," should first of all establish the connection between individual characteristics of the man-operator, time spent on his training (instruction), and expected effectiveness of performance. At the same time there is the possibility of determining general behavior patterns peculiar to the particular training method, of substantiating its staging and times, and, most important, of anticipating the possible effectiveness of future actions. These relationships, in many cases, also help to correctly anticipate the group work of operators.

The following, very simple, equation was proposed as far back as 1907[13]

$$y = a + be^{-cx}, \tag{1}$$

where

y is the quantitative criterion of assimilation;

a is the limit of assimilation for an infinitely large number of exercises;

b, c are constants; /202

x is the quantitative characteristic of the exercise, expressed in definite units.

Many different analytical relationships describing the teaching process have been proposed in recent years by many researchers. But ordinarily they describe mathematically the functions of two variables; the upper limit of teaching, and the rate at which this limit is reached.

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[13] This relationship was used by B. M. Yankelevich to analyze certain behavior patterns in the operator training process. (Voprosy psikhologii, No. 3, 1968).

Hall, in the mid-1940's, obtained the most interesting results. He analyzed a great many intermediate variables, the main ones of which characterized the number of exercises, and the time factors. One of his fundamental principles, the so-called "principle of consolidation," can be formulated as follows.

"Each time the reaction of an organism with a motive for its behavior is accompanied by a condition occurring as a result of the action of the organism consolidating it there is an increase in the strength of the skill, ${}_{S}H_{R}$, with respect to the reaction caused by the components of the stimulus coinciding in time, S_C" [16].

This principle determines the relationship between the strength of the skill and the number of successive consolidations, such as exercises, training sessions, and the like. Hall postulated that this relationship can be characterized by the exponential function

$$ {}_{S}H_{R} = M(1-e^{-iN}), \qquad (2) $$

where

M is the limit the skill can achieve under the special conditions of the experiment;

i is an empirical constant determining the rate of approach of the function to the maximum;

N is the number of consolidations.

Another Hall principle takes into consideration the magnitude (quality) of the consolidation, ω, the time between the reaction and the subsequent appearance of the consolidation, T, and the time between the onset of the effect of the conditional stimulus and the appearance of the reaction, T'.

Generalizing, Hall proposed an expression describing the strength of a skill as a function of four variables

$$ {}_{S}H_{R} = M_0(1-e^{-k\omega})e^{-jT}e^{-u(T'-C)}(1-e^{-iN}), \qquad (3) $$

where

M_0 is the limit the skill can achieve under optimum experiment conditions; /203

C is a constant determining that time interval over which the optimum development of the caused reaction occurs;

K, j, u are empirical constants.

A characteristic feature of Eqs. (2) and (3) is their empirical basis. Experimental investigations, usually made using animals, provided the original materials. Although many conclusions have been confirmed with respect to man, as well, there are a number of aspects of training that are peculiar only to man. Included in these latter, in particular, are the accumulations of habits of the speech and non-speech types, training in complex activities of the sensomotor type, partial, or complete, teaching, and transfer of skills.

This is why Hall's theory cannot explain many of the important questions associated with training man.

Some papers have considered training from the point of view of the internal processes taking place in the trainee. Their authors, just as did Hall, attempt to represent the progress of the training process by the functions of many parameters. One example is the integral method of evaluating the trainability of operators, based on consideration of the set of deviations in the parameters of the controlled process, the quantitative values of physiological indices inherent in the basic information on the condition of the operator, and coordination of the functioning of the various systems in his body, as well as on the evaluation of the information processes in a closed system [3]. It has been proposed that the integral evaluation, which is a function of special criteria, be used as a generalized index for evaluating the level of operator trainability.

$$H = \frac{\sum_{i=1}^{n} A_i}{\sum_{i=1}^{n} A_i \frac{(x_i)}{(x_i \text{ perm})}}, \qquad (4)$$

where

x_i is the parameters characterizing the control process and the condition of the operator (the time the control process is in effect, the integral evaluations of the transition process, energy consumption, parameters of the final result of control, deviations from the desired control transition process, quantity of information in the control loop, electrophysiological indices for the operator, indices for emotional and physical stress, and the like); /204

$x_{i\ perm}$ is the permissible mean values of the parameters of the control process, or the values of these parameters obtained as a result of the work of a well-trained operator;

A_i is a weight factor for each of the summands, in terms of their significance.

The integral method of investigating the behavior pattern in skill formation in the man-operator is a step forward, unquestionably. However, there are inherently serious drawbacks in indices with "weight" factors, that is, in equations of the type at (4), including those based on their quantitative values, and this, naturally, limits the possibility of using these factors for practical purposes [4].

Future work on the mathematical formulation of the process of trainability must, on the one hand, continue the trend noted to take the different factors that influence the trainability process into consideration, and on the other ensure that the result is analytical relationships that are simple and convenient enough for practical use.

Two approaches to the selection of the trainability model can be observed in those papers devoted to formalization of the training process. Some authors try to consider the mechanism involved in the formation and consolidation of skills, and take up in detail the processes that do take place (the microapproach). Others give their attention only to the result of the training in terms of the actions undertaken (the macroapproach). The latter does not require complete analysis of the system investigated. The system in this case is considered to be a "black box." The microapproach proposes a detailed study of system structure, the connections between its elements, how they function, and the like.

Both approaches are mutually complementary. But there are many cases during investigations when all that is available is the information supplied to the input, and delivered to the output, of the system. This often is the case when solving problems of training groups of operators for automated control systems, when the primary practical value is the discovery of the general behavior pattern in the increase in the effectiveness of the performance of /205 the operators by virtue of their training, and, to a lesser degree, individual drops in performance effectiveness at some particular stage of the training.

Proceeding from actual practical tasks, and taking our limited knowledge of the structure and functions of the human brain into consideration, it is desirable to begin the development of the training model at the macrolevel. This not only increases the number of variables in the model, but also helps take into consideration the whole set of factors influencing the training process.

Research along these lines indicates that at the macrolevel the task posed can be carried out with the help of the cybernetic approach to the description of the training process.

1. Mathematical Trainability Model Based on the Cybernetic Description of Operator Activity

There are different methods that can be used to obtain an analytical trainability model at the macrolevel. Two such methods, the information and the differential, will be considered in what follows. Both have positive, as well as negative, aspects.

The mathematical trainability model, as has been pointed out above, will be understood to be the relationship between the index of trainability for the operator, and the factors bearing on the formation of skills needed for the successful performance of functional duties in the "man-machine" system.

Operator trainability appears as the effectiveness of the operation of the "man-machine" system. Calculation of this index when evaluating the effectiveness of system operation is extremely complicated and will not be considered here. All that need be considered for purposes of modeling is that the trainability index (here we are abstracting from other indices) uniquely determines the effectiveness of operator performance.

Let us consider the information method of constructing the analytical trainability model.

The introduction of the concept of "information," the content of which is borrowed from information theory, from the theory of the transmission of information over communication channels, to describe the training process requires first of all answers to the question of the admissibility of its use to describe operator activity. There are three groups of researchers with substantially /206 different views on this question.

Some researchers attempt to use without limitation those measures developed under information theory to analyze human activity. Others feel that the application to man of the "information" concept in the form in which it has taken shape in the theory of the transmission of information, is unjustified because it does not reflect psychological reality. "Communicators have little interest in how the information will be used upon receipt at the end of the channel. So the telegrapher collects 3 copecks a word, whether the information concerns a completely unexpected event, or whether it is information on today's data. From the 'worldly' point of view, the second telegram would contain nothing useful in the way of information [2]. Finally, the researchers in the third group feel that the "introduction of this concept in psychology does not assume the identification of the processes used by man to process the data he perceives or the corresponding processes in technical systems. The question is one of equating these processes to each other only at a definite level of abstraction, that is, at the level at which they can be quantified. Such equation is necessary primarily for solving practical problems, because man, under the conditions of automation of production processes, really is involved with the information presented in that special form peculiar to its technical sources and is included as a link in a unified information circulation system [10]." This approach to the judicious use of the apparatus of information theory to describe the human training process is the most desirable.[14]

From the point of view of cybernetics, the human body is the most complex dynamic system that can be controlled uniquely by feedback, accomplished on the basis of reprocessing of information [1].

The mechanism involved in the actions of the human operator can be presented clearly by the example of the work done by an operator engaged in semiautomatic tracking. When a new echo appears on the indicator screen the operator analyzes the situation reflected on the indicator, evaluates the number of /207
echoes already picked up by semiautomatic tracking, the assumed coordinates of the appearance of the new echo, time required to carry out the assignment, and the like. The operator, relying on his knowledge, past experience, and the

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[14] G. Ye. Zhuravlev recently provided the most cogent analysis of this problem.

results of his analysis, develops the behavioral goal, which is to start (or not to start) semiautomatic tracking of the echo at that (or at some later) time. Simultaneous with the formation of the action program comes the formation of the anticipation apparatus, with the help of which the correspondence of the result of the actions to the assigned task is verified. The goal is realized by the effect on the corresponding controls. The operator matches the reference marker with the echo signal. In other words, he starts semiautomatic tracking of the echo.

The manner in which the operator reacts to the information, and the time he takes to do so, change during the training process. As skills accumulate the lack of coordination between the operator's functional subsystems decreases, and the operativeness of their activities from input (observation of the echo) to output (starting semiautomatic tracking of the echo) increases.

What follows is that the system (the operator), as a result of his training, makes a transition to another condition, and the training process can be considered a control process in this case.

A. A. Fel'dbaum develops a related conception. He looks at the training process as a process of interaction between instructor, student, and the training subject [14].

The interactions between student and environment can be represented in the following basic forms:

perception of the information supplied by the instructor "in finished form";

observation and comprehension of activities by classification of phenomena, recognition of examples and situations, and the building of concepts, from the simplest to ever-increasingly more complex ones. Basic in this process is the building of a system of concepts by means of internal search;[15]

experience, or experiment, associated not only with observations, but with the influence of the student on the environment as well. This process is

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[15]The results of observations are compared and "adapted" to the model of activities formed earlier, on the one hand, and the model formed is deformed, changed, or replaced by a new one as a result of new observations, on the other.

impossible without external search, including test influences on the object of training and analysis of the reactions of the object to these influences. The /208 student, when he has no past experience to fall back on, is forced to rely on the simplest of the search methods, that of "trial and error" in its most primitive form - that of a random chain of variants. Optimization of the search process [14], ensuring a more probable and more rapid achievement of the goal, becomes possible when there is apriori information, general experience, association, and analogy.

The conception of interaction between student and environment is based on the fact that training is part and parcel of the processes of obtaining, transmitting, and processing information. A comparison between the training process and the control process is completely justified if what one has in mind is the indisoluble connection of information and organization and control. Moreover, training in a sense is the classical example of the control process, the basic task of which is to preserve, or accumulate, the information in the system 6 .

It is held that the quantity of information accumulated in a system as a result of its informational interactions with the environment is the result of a definite level of organization and structure of the particular system. What this means with respect to man is that the information he receives during his training is added to that already accumulated (in this particular case the information appearing as knowledge) and has an effect on his future actions [5, 12].

Let us proceed from the assumption of the fundamental generality of the structures and schemes for controlling technical and psychophysiological systems and use the mathematical apparatus describing certain of the behavior patterns of a complex, controlled system to formalize the training process [13].[16]

What follows from the assumption made is that the lack of fitness (state of training) of the operator to carry out his functional duties is the result primarily of lack of coordination between the subsystems participating in the

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[16] There are other bases for the original preconditions for the development of mathematical trainability models [8, 15].

reception and processing of information. This lack of coordination, W, can be characterized by the entropy, H,

$$H = \alpha \log W, \tag{5}$$

where

α is the proportionality factor.

The logarithmic connection between entropy and the factor for the lack of /209 coordination conditions is accepted in statistical physics and information theory and, naturally, from the point of view of training as well. It is natural to consider the sum of the entropies of each of two successively working operators as their entropy, and, at the same time, the number of lack of coordination conditions for the two operators is equal to the product of the number of their lack of coordination conditions, and this is in complete concordance with Eq. (5).

Reduction in W can be obtained by the introduction of control, and this is associated with the processing and use of information. At the same time, reduction in lack of coordination is directly proportional to the quantity of information used in the control process.

What this means in terms of the operator will be seen from what follows. As already has been pointed out, the operator is a complex dynamic system consisting of a great many functional subsystems, the coordination of which is poorly expressed prior to the beginning of training. The associations begin to take on some coordination with the beginning of this process, and the coordination between the different subsystems improves, so that trained operators can more effectively perform their functional duties, and do so with less expenditure of energy.

The quantity of controlling (training) information processed and used by the operator to coordinate his activities can be expressed by the reduction in entropy

$$I = H_* - H = a \ln \frac{W_*}{W}, \tag{6}$$

from whence

$$W = W_* e^{-I/a}, \tag{7}$$

where

W* is the lack of coordination in the activities of the operator (lack of coordination within the individual subsystems of the organism, as well as between them), corresponding to entropy H_*.

Lack of coordination in operator actions results in errors, and reduces his effectiveness. The relationship between operator effectiveness, Q, and lack of coordination in his activities, can be written in the form

$$Q = Q_{max}[1 - f(W)], \tag{8}$$

where

Q_{max} is the effectiveness of the work of the operator with minimum lack of coordination in his activities; /210

f(W) is some function determining the loss of effectiveness in the work of the operator because of lack of coordination in his activities.

Let us take

$$f(W) = cW^d, \tag{9}$$

where

c and d are some constants.

Using Eq. (7) and Eq. (9), we obtain

$$Q = Q_{max}(1 - cW_*^d e^{-Id/a}). \tag{10}$$

Setting

$$cW_*^d = W_0 \quad \text{и} \quad a/d = I_0,$$

we obtain

$$Q = Q_{max}(1 - W_0 e^{-I/I_0}), \tag{11}$$

where

W_o is the original lack of coordination in the operator's activities;

I_o is a constant characterizing the operator's capacities with respect to reception, processing, and use of the controlling information.

Lack of coordination in operator activities (lack of coordination in the functional subsystems)

$$W = W_0 e^{-I/I_0} \tag{12}$$

can be defined as a measure of the change in his condition from some optimum condition ensuring maximum work effectiveness.

What follows from Eq. (11) is that the relationship between the effectiveness of the operator's work and the quantity of controlling information is an exponential function, the form of which is shown in Figure 1a.

The basic difficulty in the practical use of Eq. (11) is in the need to evaluate the quantity of information received and processed by the operator during coordinated activities, and the significance (value) of that information as well, in order to ensure that the training process will have a specified effectiveness. The lack of practically suitable methods for solving this problem necessitate the introduction of additional limitations and assumptions.

Let us assume that the level of trainability of the operators, γ, can /211 be characterized by the quantity of controlling information processed by the operator; that is, that $\gamma = \alpha I$, where α is some function. Eq. (11) then will take the form

$$Q = Q_{max}(1 - W_0 e^{-\gamma/\gamma_0}), \qquad (13)$$

where

Q is the effectiveness of the work of the operator trained to level γ;

W_0 is the original lack of coordination in the operator's activities;

γ_0 is a coefficient characterizing the capacity of the operator to be trained (in units of information measurement).

This mathematical model can be used to analyze training processes if it is assumed that the level of training is a gradual one (γ_i can correspond to the highest level of training, for example).

Eq. (13) can be converted if it is assumed that the degree of operator training is proportional to the time spent on his training for the training system used; that is, $\gamma = \beta t$, where β is some function[17]

$$Q = Q_{max}(1 - W_0 e^{-t/t_0}), \qquad (14)$$

where

$t_0 = \gamma_0/\beta$ is a coefficient characterizing the capacity of the operator to be trained (in units of time).

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[17] The function β, in the most general case, characterizes the system of training adopted, the degree of mutual correspondence between training conditions and future work, and a number of other factors that influence the formation of the operator's knowledge and skills.

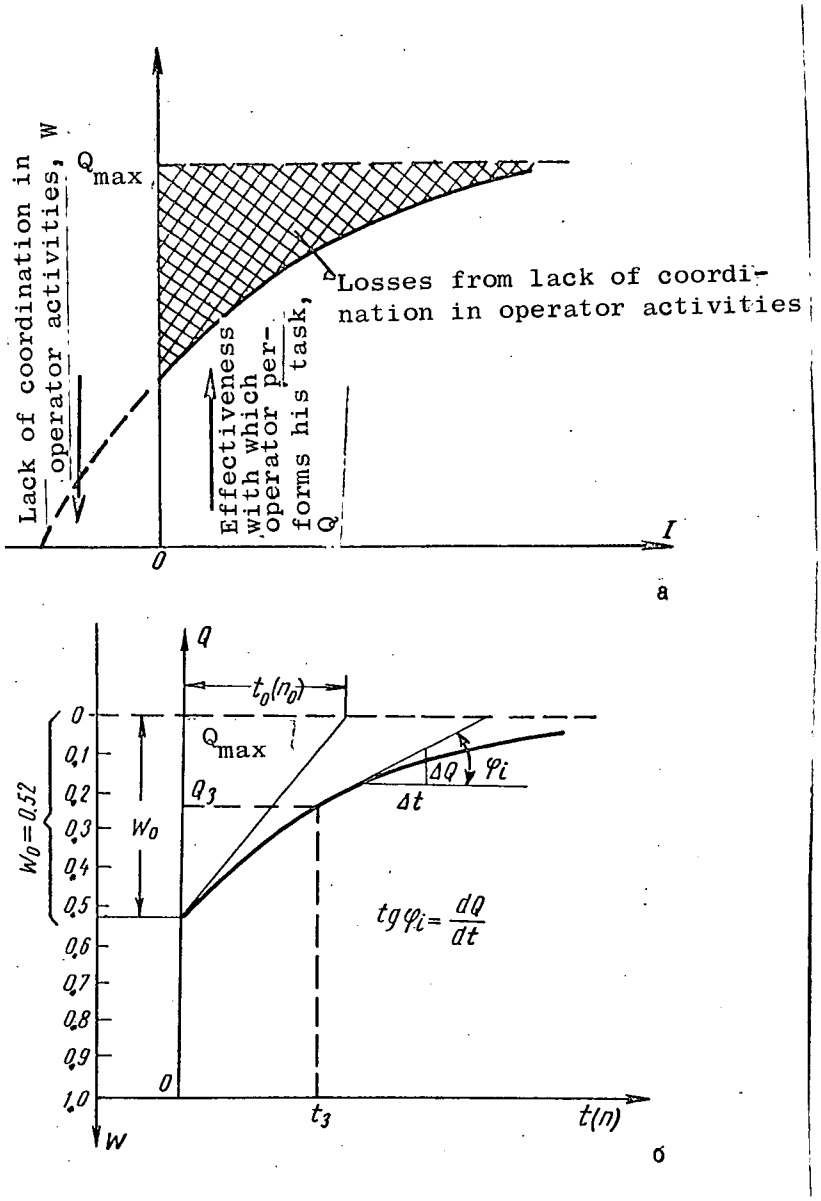

Figure 1. Effectiveness of operator's work in terms of a - quantity of controlling information used; b - training time.

Eq. (14) provides a sufficiently graphic picture of the growth in the effectiveness of the operator's work during his training (Figure 1b).

The time spent on training in many cases is directly proportional to the number of training sessions, so there is another way to write Eq. (14) that often proves to be more convenient for practical purposes

$$Q = Q_{max}(1 - W_0 e^{-n/n_0}), \quad (15)$$

where

n is the number of training sessions;

n_0 is a coefficient characterizing the capacity of the operator to be trained (it can be evaluated in terms of number of training sessions). /213

Let us consider the differential method of constructing the trainability model, understanding the training process to be the doing of the exercises (the tasks).

Let us assume that the training process has been organized, and is proceeding normally. Drills do not exceed the physiologically permissible limit in length, and mental and physical loads are within critical limits, beyond which the effect of further training would be negative. A number of natural considerations and assumptions can be deduced from these conditions.

1. The index of state of training should be a continuous function of time spent on training. The index of state of training can be increasing (the probability of successful completion of the exercise, for example), or decreasing (time to do the exercise, number of permissible errors, and others, for example). In any case, the additional training time (given normal progress of the training process) can only serve to upgrade the value of the index (increase, or decrease, respectively).

2. Any index of state of training should have limits that can be reached when time is unlimited, and when time is unlimited for lack of consolidation; that is, there should be limits on state of training, and limits on loss of skills, for any exercise for any index.

3. The level of state of training achieved earlier will be lost if there are no repetitive training sessions provided. The values of the increasing index of state of training will decrease, those for the decreasing index will increase.

4. The rate of training, or of loss of skills (the effect of a single drill, of one day of interruption) will be decreased as the limit is approached. This fact is observed throughout the training process.

The hypotheses thus advanced lead to the conclusion (the index of state of training is assumed to be increasing) that drills (training sessions) over a short time span Δt, change the value of the index of state of training by a magnitude proportional to the difference between the achieved level of state of training and its limits; that is

$$Q(t+\Delta t)=Q(t)+K[Q_{lim}-Q(t)]\Delta t$$

or

$$\Delta Q=K[Q_{lim}-Q]\Delta t \quad \text{(214)}$$

where

Q_{lim} is the limit for the index of state of training;

K is the proportionality factor.

The relationship obtained reduces to a differential equation expressing the analytical trainability model in terms of the particular exercise

$$\frac{dQ}{dt}=K(Q_{lim}-Q). \quad (16)$$

The solution of this equation depends on the form of the proportionality factor, which determines the rate of training. What should be taken into consideration in the general case is that the rate of training and the acquisition of skills will depend on:

previously acquired knowledge and skills;

time spent on study and on the acquisition of skills in terms of the particular exercise;

the acquired level of state of training in terms of the particualr exercise;

the specific characteristics of the student (individual, or collective);

procedures used in the drills and training sessions;

specific features of the particular exercise.

The first, and the last three factors have no effect on the form of the solution of Eq. (16). Their effect shows up in the quantitative value of the proportionality factor.

The second and third factors bring into consideration the proportionality factor for the time function, t, and achieved level of state of training, Q. The general solution of Eq. (16) therefore can be written

$$\frac{Q_{lim}-Q}{Q_{lim}-Q_0} = e^{-I(t)},$$

where

Q_0 is the initial value of the index of state of training;

$$I(t)=\int_0^t K(t)dt.$$

Limiting the linear term of the expansion of the function I(t) to a power series, we obtain the simplest form of the trainability model for the individual exercise as /215

$$\frac{Q_{lim}-Q}{Q_{lim}-Q_0} = e^{-Kt}$$

or

$$Q = Q_0 e^{-Kt} + (1-e^{-Kt})\, Q_{lim} \qquad (17)$$

Introducing the notation

$$W_0 = \frac{Q_{lim}-Q_0}{Q_{lim}}, \quad t_0 = \frac{1}{K} \quad \text{and} \quad Q_{lim} = Q_{max},$$

we obtain the analytical form of the trainability model similar to Eq. (14).

A comparative analysis of Eqs. (2) and (14) is definitely of interest. Despite an outward similarity, they have significant differences.

First of all, the constant M in Eq. (2) is treated as the maximum for the skill effect. In other words, a ceiling is imputed to each operator, one he cannot exceed (this premise, unfortunately, is at the basis of the overwhelming majority of analytical models proposed for describing the trainability process).

This assertion is not strictly so, however, because in principle there is no basis for doubting that an individual satisfying the requirements imposed on the operator in a particular vocation can be trained to the required level.

The whole question reduces simply to the time needed for training, and the method used for that training. Not all candidates will be capable of mastering the specialty with the same perfection, or at the same time, because

of individual differences if the operator's training period is limited. The ceiling can be spoken of from this point of view, of course, bearing in mind the limited training periods. Eq. (14) is based on the potentials of the "ideally functioning" operator, Q_{max}, which, in principle, any candidate who has passed the vocation selection successfully, can approach. The maximum potentials of specific operators are considered in this case only from the point of view of comparing them with the "ideally functioning" operator at a particular stage /216 of training for the same training conditions.

The assumption that each individual has a ceiling does away with the practical significance of Eq. (2), because the qualitative evaluation of this constant requires a long period of study of each candidate. The presence of a single ceiling for the "ideally functioning" operator for all individuals makes it possible to use a single index, one that can be determined from the results of experimental investigations, or theoretically based on an evaluation of the capabilities of a concrete "man-machine" system.

Second, Eq. (14) can be used to evaluate the differences in operators with the original level of training taken into consideration (because of the introduction of the parameter W_0); that is, with consideration of knowledge, ability, and skill acquired earlier that will, to some extent, merge with future operator activities. Eq. (2) does not take into consideration the degree of lack of coordination in the activities of the operator at the initiation of training because a zero level is imputed for him in all cases. This obviously would be correct when analyzing the development of skills in animals, but unjustified with respect to man, despite the fact that in practice one encounters cases when $t = 0$, and $W_o \neq 0$, $Q = 0$. It is customary to find these cases in systems the effectiveness of which depend to an incomparably greater degree on the quality of the operation of the machine links in the system than on man. For these systems the index of effectiveness shows little response to changes in the quality of the work done by the operator, particularly during the initial stages of his training.

2. The Use of the Mathematical Trainability Model for Practical Purposes.

As already has been pointed out, the effectiveness of the work of the operator in a concrete system is determined primarily by his individual qualities, which can be characterized by the initial lack of coordination in his activities, W_o, and by the coefficient of trainability, t_o; The quantitative values of these parameters therefore must be known in order to evaluate and forecast the possible effectiveness of the operator's work.

The first parameter can be determined from initial acquaintance of the future operator with his specialty. So far as the second parameter is concern- /217
ed, special observations of the individual's work for some period of time are required for its assessment.

The question of forecasting the effectiveness of the work of a future operator arises for the first time during selection. The values of the parameters W_o and t_o therefore should be determined for each individual at the selection stage [9].

The mathematical trainability model also should be used to evaluate the operator training system. With data on a contingent of personnel to be trained available (knowing t_o and W_o for each individual), we can determine the time required to train specialists to the required level, t_{tr}, to estimate the funds and materials that will have to be expended for this purpose, R, to arrive at an opinion as to the possible level of training for a limited training time, Q_{ex}, and the like.

The time that will be needed to train the operator to a level ensuring the required effectiveness of his work, $Q = KQ_{max}$, is equal to

$$t_{tr} = t_o \log [W_o/(1-K)], \tag{18}$$

or, in accordance with Eq. (15)

$$n_{tr} = n_o \log [W_o/(1-K)]. \tag{19}$$

What follows from Eq. (18), for example, is that the time required to train the operator to a level ensuring effectiveness of his work of at least 90 percent of the maximum (K = 0.9) is equal to

$$\text{tr} \qquad \text{o} \qquad \text{tr} \tag{20}$$

Figure 2 shows Eq. (19) for certain values of the parameters t_o, W_o, and K.

There are cases of no significant change in the effectiveness of an operator's work during the initial stage of training. The mathematical trainability model for these operators will differ somewhat from Eq. (14) because of the inclusion of a new parameter, the so-called developmental time, τ_o. The time required to train operators who require a given developmental period can be computed from

$$\tau_{tr} = \tau_0 + t_0 \log[W/(1-K)]. \tag{21}$$

Knowing the time that will be needed to train the operators, we can make an advance estimate of the money and material that will be needed for the purpose. If r, the average cost of training an operator, is known, the total training cost can be figured quite simply as /219

$$R = t_{tr} r . \tag{22}$$

There are two ways to go about training operators when their individual capabilities are known. One is to train all candidates for a given period of time (by a redistribution of training hours according to individual peculiarities) and have all of the trained operators complete training at the same time. The other is to organize sequential training of specialists, beginning with the candidate with the lowest t_{tr}. This results in a sequential addition of operators to the collective operating the system.

The particular choice will depend on concrete requirements in augmenting the collective with operators, and on where the training is done, in classrooms, or on the job. The student group should be made up of candidates requiring approximately the same training times, and this is true regardless of the choice. When training time, for whatever reason, is limited in advance by some value t_z, it is necessary to evaluate the expected effectiveness of the future activities of operators trained within that period of time.

Naturally, each candidate will reach a different level of mastery after identical training times, and the level will depend on individual peculiarities.

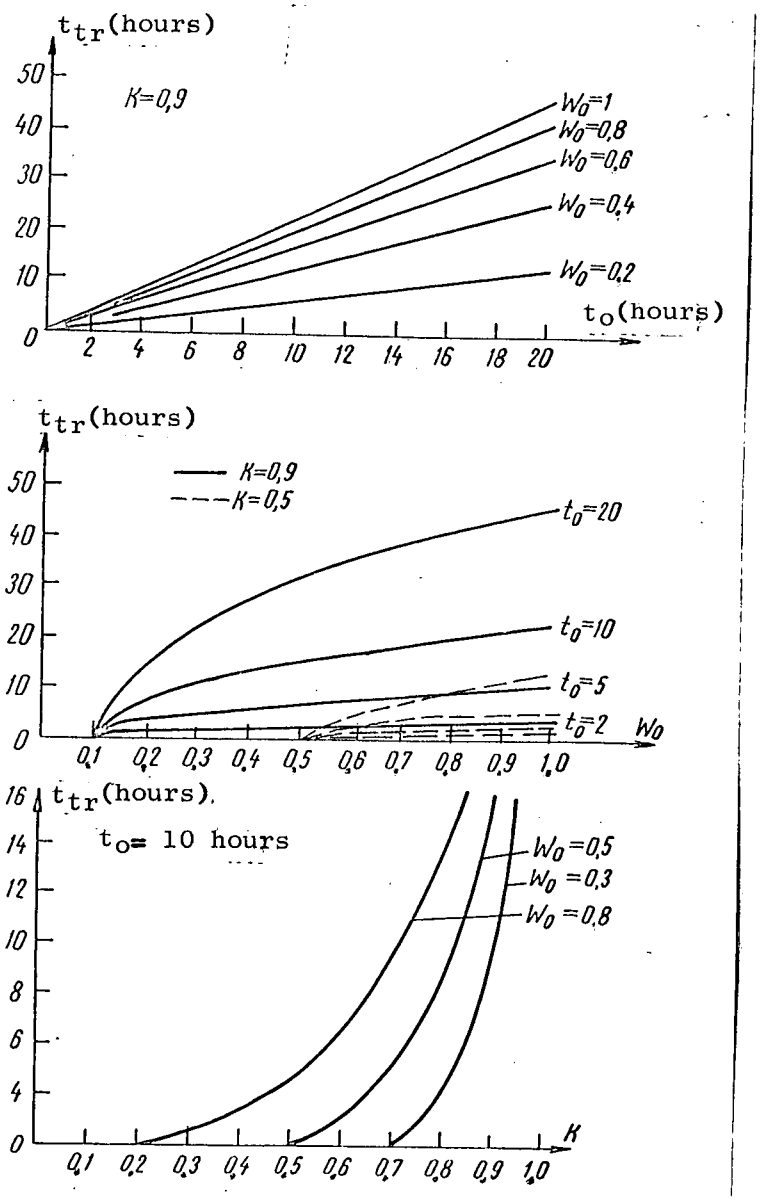

Figure 2. The relationship $t_{tr} = f(t_o, W_o, K)$.

The following expression can be used to evaluate this expected effectiveness

$$Q_{ex} = Q_{max}\left(1 - W_0 e^{-\frac{t_z}{t_0}}\right). \quad (23)$$

The use of analytical trainability models is desirable for reasons other than those concerned with individual operators. It is quite proper to introduce the concept of the initial lack of coordination in the work of a collective of operators, W_c, and the capacity of this collective to be trained, t_c. In this case the expression /220

$$Q_c = Q_{max\ c}(1 - W_{oc}e^{-t/t_{oc}}) \quad (24)$$

makes it possible to evaluate the effectiveness of the work of the collective during the training process, and Eqs. (18)-(23) to obtain the initial data for planning and forecasting the training system for this collective.

Analysis of the "man-machine" system is unthinkable without an evaluation of the relationship between its effectiveness and the level of training of the operators. One variant of this evaluation is a determination of the increase in system effectiveness in terms of a rise in the level of operator training.

The solution of this problem in general form is very complex because of the need to take into consideration the interaction of results of operator work and system effectiveness.

There is a relatively simple expression for the coefficient of response of the systems to operator training level in the case of simple systems in which the algorithm of operator activity excludes the interaction, as well as in the case of systems run by one operator

$$\gamma = T_o/t_o, \quad (25)$$

where

T_o is the time required by the operator to master the specialty (system).

Eq. (25) is based on the assumption that the mastery law is exponential. This assumption is quite proper because the influence of the accumulation of information on the increase in effectiveness of activities can be described by an exponential dependency [13].

Obviously enough, when γ is small the level of operator training will have practically no effect on system effectiveness, so the task of operator vocation selection is greatly simplified in this case. When γ is large the level of operator training plays a significant role in increasing system effectiveness.

There are a number of cases when γ also permits a judgement to be made of concrete peculiarities in the "man-machine" system as created, or planned, of level of automation, and of the quality of the match between the machine and /221 man links in the system.

The mathematical trainability models can be used to substantiate the maximum values of the most important parameter characterizing the ability of man to master a specialty for cases when training time is limited

$$t_{o\ lim} \leq t_s / \log [W_o/(1 - K_s)] \qquad (26)$$

where

$K_s = Q_s/Q_{max}$;

Q_s is the specified level of effectiveness of work done by an operator completing the full training cycle.

Figure 3 is the graph of Eq. (26).

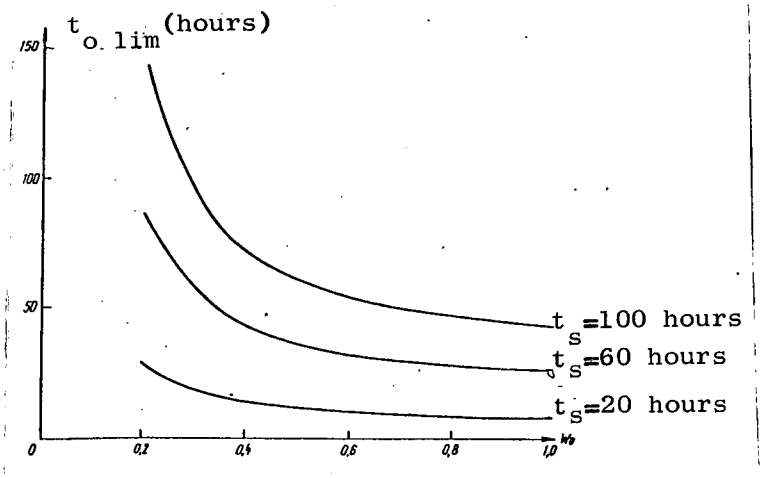

Figure 3. Graph of t_o limits.

In conclusion, it should be pointed out that the mathematical trainability model considered does not take into consideration the internal structure of the training process, hence does not disclose many of the peculiarities of this process. Consideration of the internal structure of the process of accumulating knowledge and skills requires consideration of questions of training at the microlevel.

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